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THE TIDES: THEIR CAUSES AND REPRESENTATION

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Historical Note on the Tidal Problem

THE so-called problem of the tides has for ages engaged the attention of observing and thinking men. Before Newton established the law of universal gravitation, the whole subject was surrounded with an air of mystery, although the fact had long been recognized by many that in some manner the tides are governed by the moon or the moon and sun. Such views were held by Pytheas of Massilia, Seleucus of Babylonia, Posidonius the Stoic philosopher, Cæsar, Cicero, Strabo, Seneca, Pliny the elder, Lucan, Claudianus and Macrobius.

The ancients say little as to the agency whereby the moon is enabled to exert an influence upon the waters of the globe; but winds produced by the moon, vapors surrounding the moon and the special power of the moon to replenish moist bodies, are severally mentioned as being the probable means.

However, before Newton's great discovery, several philosophers had gone so far as to suggest or assert that the tides are due to an attractive force of the moon analogous to magnetic attraction. Among these were Scaliger, Gilbert, the College of Jesuits at Coimbra, Antonio de Dominis, Stevin and especially Kepler.

Of course, not all ancient or medieval theorists admitted the moon to be the cause of the tides. Some of the many other causes brought forward were: The discharging of rivers into the sea; variations in depths and densities of the sea; the surface of the sea not being everywhere upon the same level; the respiration of the earth; submarine caverns; submarine heat; submarine vapors, exhalations, or fermentations; power exerted by a supernatural being; whirlpools and eddies; and the non-uniform motion of the earth or of its various parts.

When Newton had made public his capital discovery, and had shown that the magnitudes or ranges of the tides increase and decrease in accordance with the varying attractions of the moon and sun, the tidal problem was supposed to be nearing a solution. Indeed, Newton thought that he could see in the observed times of tides upon certain shores a justification of his theoretical considerations. His work, however, was only a beginning. Since his time, eminent mathematicians, astronomers and physicists—including Bernoulli, Maclaurin, Euler, Lalande, Laplace, Young, Lubbock, Whewell, Airy, Ferrel, Kelvin, Darwin, Lévy and Hough—have addressed themselves to this subject; while others, like Lagrange, Stokes, Rayleigh, Lamb and Poincaré, have dealt rather with the underlying mathematical and physical problems.

Since it has been universally recognized that the tides result from the attraction of the moon and sun, the popular mind has taken little interest in the manner in which these forces operate in order to produce the tides. The apparent hopelessness of the task has doubtless deterred many investigators from devoting to it a full measure of their attention. In fact, as will be shown below, there is no such thing as "the tidal problem" analogous to the astronomers' "problem of three bodies." The tide involves a number of problems, and to even discover what these problems are requires a good knowledge of the forms, sizes and depths of the oceans, together with a knowledge of the tide-producing forces. The observed tides themselves render great assistance in this matter; for their times and ranges indicate the ways in which the various oceans probably oscillate, and so, in a measure, the underlying tidal problems requiring solution.

General Belief in a Westwardly-progressing Tide Wave

Various theories were instrumental in leading to the belief of a general westward progression of the tide. As before the Copernican system of astronomy became known or generally accepted, the tides were made to accord with the Ptolemaic system then prevailing, so for some time before and after the publication of Newton's "Principia," the tides were made dependent upon the vortices of Descartes's theory.

The Ptolemaic system of astronomy assumed the center of the earth to be the fixed center of the universe around which revolved a series of concentric spheres. The outermost of these was styled the *primum mobile;* this by its westward motion imparted westward motion to the stars and other heavenly bodies, to the atmosphere, and even to the waters of the oceans. And so before the law of gravitation was established, the notion became prevalent that water had a westward motion (*ab oriente in occidentem* or *ab ortu in occasum*) around the globe; and because the flood stream, rather than the ebb, was the one chiefly considered, the flood stream (and so the progression of the tidal wave) was commonly supposed to partake of this westward motion. The

theory of a westerly motion of the waters thus had its origin in the assumed motion of the *primum mobile*. The flood tide was associated with this westward motion by Scaliger and Bacon. Kepler also asserts that the flood has a westerly direction, although, as already stated, he attributes the tides to the attraction of the moon.

Descartes's vortex theory also gave a westward progression to the tidal wave because he assumed that low water would always occur when the moon crossed the local meridian.

Newton, Bernoulli and Laplace evidently contemplated tide waves progressing westward around the earth, completing the circuit in 24 lunar hours, or 24 hours and 50 minutes solar time, although they were aware that the land masses must produce many irregularities in this hypothetical motion.

In order to see how any tide wave progresses, it is necessary to reduce to a common time. This is generally taken as Greenwich lunar time. Consequently, if tides in a given locality are found to follow the meridian passage of the moon by a certain interval (expressed in lunar hours), this interval must be increased by the longitude, expressed in hours, if the place be in west longitude and decreased if in east longitude. Places having high water at the same tidal hour are said to lie upon the same cotidal line.

The first extensive charts of cotidal lines were constructed by Whewell about 75 years ago; and these charts, or these charts slightly modified, have been in common use in atlases and astronomies ever since.

The Importance of Stationary Waves suggested

The analogy between the tides and the oscillatory motion of water in a vase, or other vessel, had been noted by many even before the moon's attraction had been universally recognized as the principal and primary cause of the phenomenon. But in order that the water should oscillate, it must first be disturbed from its position of equilibrium. Galileo imagined that he had found this necessary disturbance in the non-uniform motion of different parts of the earth as it rotates upon its axis and revolves about the sun.

César d'Arcons (1667) supposes the solid earth to move a short distance back and forth along its axis, thus causing the flood in the northern hemisphere to appear to move from south to north and the ebb in the reverse direction. According to his views the entire Atlantic Ocean is a huge vessel of water, the surface rising and falling considerably at the two ends (*i. e.*, in high latitudes), but having little vertical motion near the middle (*i. e.*, in equatorial regions), where he logically infers the horizontal motion to be great.

John Bryanston (1683) supposes the moon to produce in the earth a small east-and-west libration, not detected by astronomers, and this

motion of the earth to cause the waters of the oceans to oscillate like water contained in vessels of various shapes and sizes.

While not questioning the fact established by Newton that the tides are primarily due to the attraction of the moon and sun, Admiral Fitz Roy attempts to explain the tides upon the assumption of stationary waves extending in an east-and-west direction across various portions of the several oceans. His wide experience as a navigator had familiarized him with the fact that throughout some extended regions of the ocean, the tides occur at nearly one and the same time; also that even for islands remote from the land, the amount of rise and fall is quite various.

Sir George B. Airy was the first person to make an extensive mathematical study of wave motion implied in tidal phenomena. While he does not point out how the ocean tides are produced, he shows that certain dependent bodies of water, and in particular the Irish Sea, must contain stationary waves. He establishes the theoretical result that the tides in a north-and-south canal extending from the equator to either pole must consist of a stationary wave.

William Ferrel suggests that, because of their unusual size, the tides of the North Atlantic may depend upon stationary waves extending in an east-and-west direction across the ocean; and, in particular, upon one extending between the coasts of Ireland and those of Newfoundland.

These, and other writers who have expressed similar views, failed to consider that an imperfectly bounded strip of the sea must have considerable width (as well as a suitable length) in order to make a stationary wave possible. They also failed to make any connection between the known tidal forces and the times of the tide.

This brings us to the subject proper, which involves an approximate explanation of the dominant ocean tides, it being manifestly unreasonable to expect accurate mathematical solutions of the problems involved.

It should be noted in passing that although Dr. Berghaus propounded no theories concerning the tides, his cotidal chart constructed in 1889 marks a radical departure from those previously constructed, and is in itself highly suggestive.

The Tide-producing Forces

The tide-producing forces of moon and sun can be computed from well-established astronomical data, and there are no uncertainties connected with their determination, at least to a moderate degree of refinement. In this place it is necessary to say only a few words descriptive of these forces. The tide-producing force of the moon upon a particle of unit mass is the difference between the moon's attraction upon this mass and upon a unit mass situated at the earth's center; or

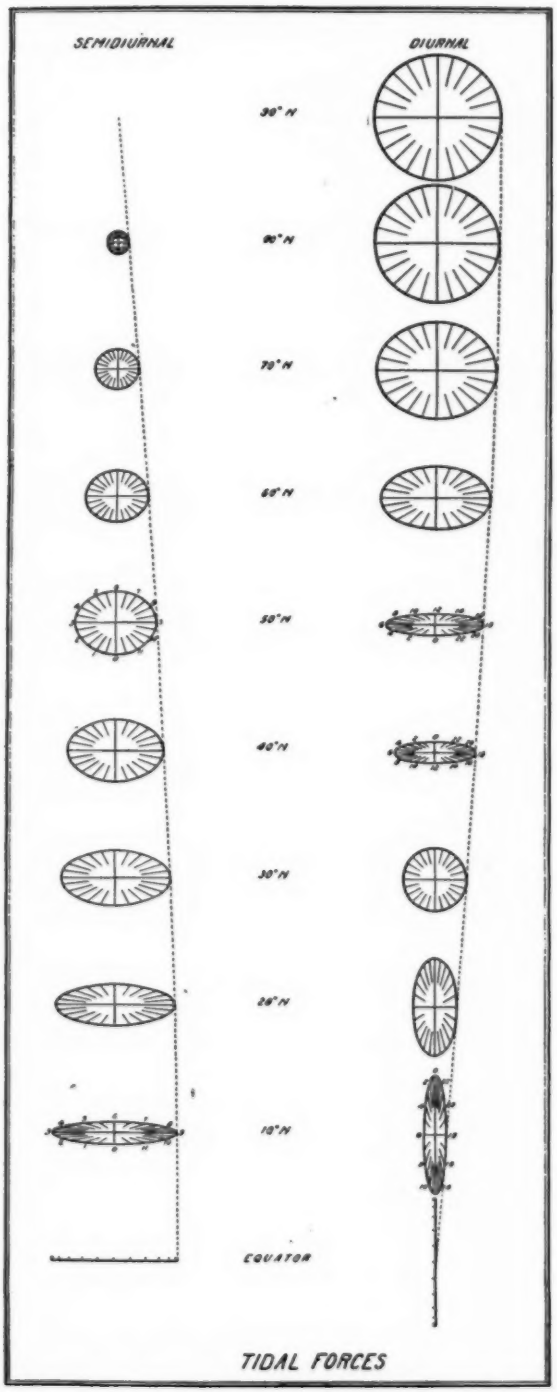


FIG. 1. The diagram shows the magnitude and direction of the tidal forces at each half lunar hour for various north latitudes. Such a force is represented by a line drawn from the center to the periphery of the ellipse having the given latitude. At the equator the mean value of the semi-diurnal force at 9 or 3 o'clock is equal to one thirteen-millionth part of the force of gravity at the earth's surface. The diurnal forces shown in the figure are those occurring upon the day when the moon's declination is greatest either north or south.

it is the difference between the moon's attraction upon the given unit mass and the moon's attraction upon the entire earth divided by the mass of the earth. Because the depths of the oceans are small in comparison with the length of the earth's radius, and because of the smallness of the tidal forces, only the horizontal components of such forces are effective in the production of tides; and so these may, without impropriety, be spoken of as the tidal forces.

The vertical forces alter the intensity of the earth's gravity upon the waters of the ocean in a way similar to the alteration which would be occasioned were the density of the waters to undergo a fluctuation having a range of less than one ten-millionth part of itself. Now the greatest known ocean depth occurs near Guam Island and measures 5,269 fathoms or 31,614 feet; and it is obvious that the small density fluctuation just mentioned, and so the vertical forces, can create no sensible disturbance in the existing ocean.

For simplicity's sake, we shall here ignore that alternation in the forces which depends upon the declination of the moon, and is responsible for what is called the "diurnal inequality" in the tides. We shall also, as a rule, ignore that portion of the tidal forces resulting from the sun's attraction.

It is evident that at moonrise or moonset at a given point or locality upon the earth's equator, the horizontal forces vanish because the given point is then (very nearly) as remote from the moon as is the earth's center. On account of the moon's parallax, the moon at the times of rise or set does exert a downward disturbing force at the given point or locality; but, as already stated, this does not concern the tides. When the moon is on the meridian above or below the horizon, the disturbing force is all vertical and so the horizontal component does not exist. Therefore the tidal forces vanish four times during each lunar day. From moonrise to moon culmination, the force is directed eastward; and from culmination to moonset, westward. Also from moonset to lower culmination, the force is directed eastward, and from lower culmination to moonrise, westward.

For a point not upon the equator, there is also a meridional periodic force. In north latitude this force has its maximum southward value at the time of either culmination, and its maximum northward value at moonrise and moonset. The reverse of this is true for a point situated in the southern hemisphere.

In accordance with what has been said, a suspended plumb bob will, at the equator, make two complete oscillations daily in an east-and-west direction. The average amount of deviation either way from its undisturbed position will be about one thirteen-millionth part of the length of the line measured from the point of suspension to the center of inertia of the bob.

Equilibrium or Lake Tides

The surface of a small and sufficiently deep body of water will arrange itself normal to the direction of apparent gravity; that is, normal to the direction of terrestrial gravity when disturbed by the moon and sun, or, in other words, normal to the disturbed plumb line. If such a body of water be situated upon the earth's equator, high water will occur at its east end three lunar hours before the upper or lower culmination of the moon and low water, three hours after such times. When it is high water at the east end, it will be low water at the west end, and *vice versâ*. The amount of the rise and fall (*i. e.*, the range of tide) at either end will be one thirteen-millionth part of the length of the body of water. If the body of water be not upon the equator, the range of tide will be somewhat less, and the times of high water around its margin will be progressive, following the order of the hands of a watch in the northern hemisphere and the opposite order in the southern. At the center of gravity of the surface of such a body will be a point having no rise and fall of tide, and so styled a "no-tide point." Tides produced in this way are called "equilibrium tides"; the minute tide found in Lake Superior constitutes an excellent example of this class. The observed rise and fall of the lunar tide at Duluth amounts to 1.6 inches, while the value computed directly from the forces amounts to 1.4 inches.

As commonly taught in schools and colleges, the expression "equilibrium tide" is used to denote a fluctuation in the ocean's surface resulting from an instantaneous arrangement of all water particles such that the surface of the ocean is everywhere apparently level, or normal to the direction of the earth's gravity when slightly disturbed by the action of the moon. It is taught that, but for the resistance caused by the continents and ocean bed, high water at a given place would occur when the moon crosses the local meridian. As may be gathered from what follows, this conception is fundamentally wrong. The semidaily fluctuation of the ocean's surface does not even approximate towards a surface of equilibrium, because the inertia of the water, and the shallowness of the ocean, when its depths are compared with its horizontal dimensions or with the distance from the surface to the center of the earth, prevent such adjustment from taking place in anything like the half-daily period.

Oscillatory or Ocean Tides

Most tides are not equilibrium tides; they are waves either stationary or progressive. The forces just described act upon portions of the oceans which are susceptible of taking up stationary oscillations having about the same period as the period of the forces. In this way the dominant tides originate. But irregularities in depth and coast line, particularly openings through the latter, cause the tides generated in

these ocean basins to send off progressive waves into other parts of the oceans and into seas, gulfs, bays and tidal rivers.

By a stationary oscillation is meant a mode of motion which can be readily set up and maintained in a tank, vase or other artificial vessel of water. High water at one end of a rectangular body of water occurs when it is low water at the other end, if the simplest mode of oscillation be under consideration. Between the two ends is a line, styled "nodal line," along which there is neither rise nor fall but across which the horizontal motion of the liquid particles is comparatively great. In order that a large and regular oscillation may be maintained, it is necessary that the natural period of the basin of water be very nearly equal to the period of the applied forces: just as a resonator must have certain dimensions if a particular musical tone is to be reinforced by its presence. An oscillation is best sustained if the phases (or time-angles) of the forces, all parts of the system being considered, agree, as well as may be, with the phases of the velocities of the water particles. This furnishes a clue to the times of the tides when one knows the times of the vanishing of the forces.

Obviously, if two rectangular basins performing simultaneous oscillations in accordance with their simplest modes be put together end-to-end, and the partition between them removed, the whole body may be made to so oscillate that high water will occur simultaneously at the two ends, while it will be low water over the central portion. The nodal lines will remain in the same positions as before, crossing the individual bodies midway between their real and virtual ends, or the new body at points one quarter of the body's length from either end. The individual bodies each comprise a half wave-length of the whole-wave system to which they now belong. The oscillation in each of the individual bodies is said to be "uninodal" and that in the whole body, "binodal."

No-tide Points

Points shown upon the charts (Figs. 5, 6 and 7) from which the cotidal lines radiate, are no-tide points; that is, points at each of which there is no rise and fall of tide. In the oceans these points are due to the fact that the times of the tides around them and which times are dependent upon stationary or progressive waves, or both, must take successively all values from one to twelve, because in open water sudden changes in time can not occur.

In narrow arms of the sea, no-tide points may result from dependent stationary oscillations influenced by the deflecting force of the earth's rotation. This, for the northern hemisphere, is such that if we always face the direction towards which the flood or ebb stream is flowing, water will be piled up upon the side of the channel then situated upon the right, and drawn away from the opposite bank. The reverse of this occurs for channels situated in south latitude.

Atlantic-Ocean Tides

A body of water resembling the artificial one just described is the portion of the Atlantic Ocean (shown by one form of shading) extending from South America to southern Greenland and resting against the western coast of Africa and Europe. A section of this basin or

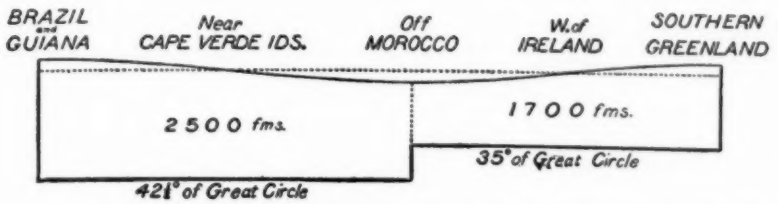


FIG. 2. This diagram shows the binodal oscillation going on in the North Atlantic Ocean. When it is high water at either end, it is low water off Morocco and *vice versâ*. The depth of the southern portion being greater than the depth of the northern, a half wave-length in the former exceeds a half wave-length in the latter—the period in each case being very nearly 12 lunar hours.

system is shown by means of a diagram (Fig. 2). One nodal line passes near the Cape Verde Islands and another lies westerly from Ireland. When it is high water on the coasts of Guiana and Brazil, it is also high water around southern Greenland, and it is then low water along the coast of Morocco, Spain and Portugal. The Roman numerals upon the small map of the world show that high water occurs at eight o'clock, Greenwich lunar time, for the South American and Greenland ends of this basin and at two o'clock for the central or Morocco portion. On account of the extensive openings to the eastward and northward of this basin or system, progressive waves are formed which contribute to the tides around the British Isles and Arctic Archipelago, and are chiefly responsible for the tides of the Arctic Ocean. Since progressive waves can not arise suddenly, their effects are felt over a large portion of the system now under consideration, and they tend to obscure the theoretical nodal lines which cross it.

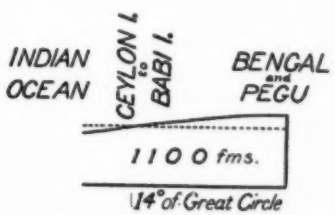


FIG. 3. This diagram shows that the Bay of Bengal measures a quarter of a wave-length to its nodal line extending eastward from Ceylon. Its tide depends directly upon that tide of the Indian Ocean which lies to the southward of the nodal line.

The tides along the Atlantic Coast of the United States are produced in the body of water which extends from this coast to the Antarctic Continent by way of Cape of Good Hope. This is shown upon the smaller chart of the world (Fig. 4) by one of the types of shading. The northern portion of this region is not greatly influenced by progressive waves because the openings through its northwestern, or United-States, boundary are not large. Consequently, the theoretical

nodal line running northeasterly from the Lesser Antilles is not obscured. Referring now to the cotidal chart of the Atlantic Ocean (Fig. 5), it will be seen that the mean range of tide, as shown by Arabic numerals, is seven feet along the coast of Georgia, between two and three feet for the Bahamas, one foot for the outer coast of Porto Rico, and little or nothing some leagues farther eastward. Hence the observational proof of the existence of one end of this nodal line.

When it is high water along the Atlantic Coast of the United States, it should be low water between Brazil and western Africa; that is, because the tidal hour is twelve for the former locality, it should be six for the latter. Doubtless such is the case for the portion of the tide depending upon the system now under consideration. But the system previously considered, viz., that extending from Guiana and Brazil to southern Greenland, gives eight for the tidal hour off the Brazilian coast. This explains why the observed times of tide between western Africa and Brazil fall between six and eight o'clock.

All along the southeastern coast of Brazil, the tidal hour is six, while west of Cape of Good Hope it is about twelve—but not exactly twelve because this locality is influenced by a progressive wave due to the existence of the Gulf of Guinea.

Farther south, along the Antarctic Continent, the tidal hour is doubtless six, but no observations are available for verifying this conclusion.

It may be noted here, and before going farther, that upon the small chart of the world (Fig. 4), the unshaded water areas are such that forces acting upon them, and them alone, can produce little tide either in such areas themselves or in other parts of the oceans. In other words, if they possess tides, these will depend upon the tides existing in such portions of the oceans as are comparatively well suited for their production. Heavy lines upon the chart indicate outer boundaries of systems. If rigid walls were erected along the outer boundaries of any particular system, the forces would incite tides of considerable size in the waters bounded by the walls and the shore lines; the tides of the system, if kept down by resistance, would nearly agree in their times of occurrence with the tides actually existing. These hypothetical bodies of water, together with such landward dependencies as have their tides occurring simultaneously with those of the body proper and upon which the forces act, are shaded by means of light parallel lines. In a particular ocean, the systems are distinguished by the directions given to the lines of shading. Double shading indicates an overlapping of systems.

The waters surrounding the British Isles have, as a rule, large tides accompanied by swift tidal streams. They depend chiefly upon the rise and fall of that part of the ocean situated to the southwestward of these isles.

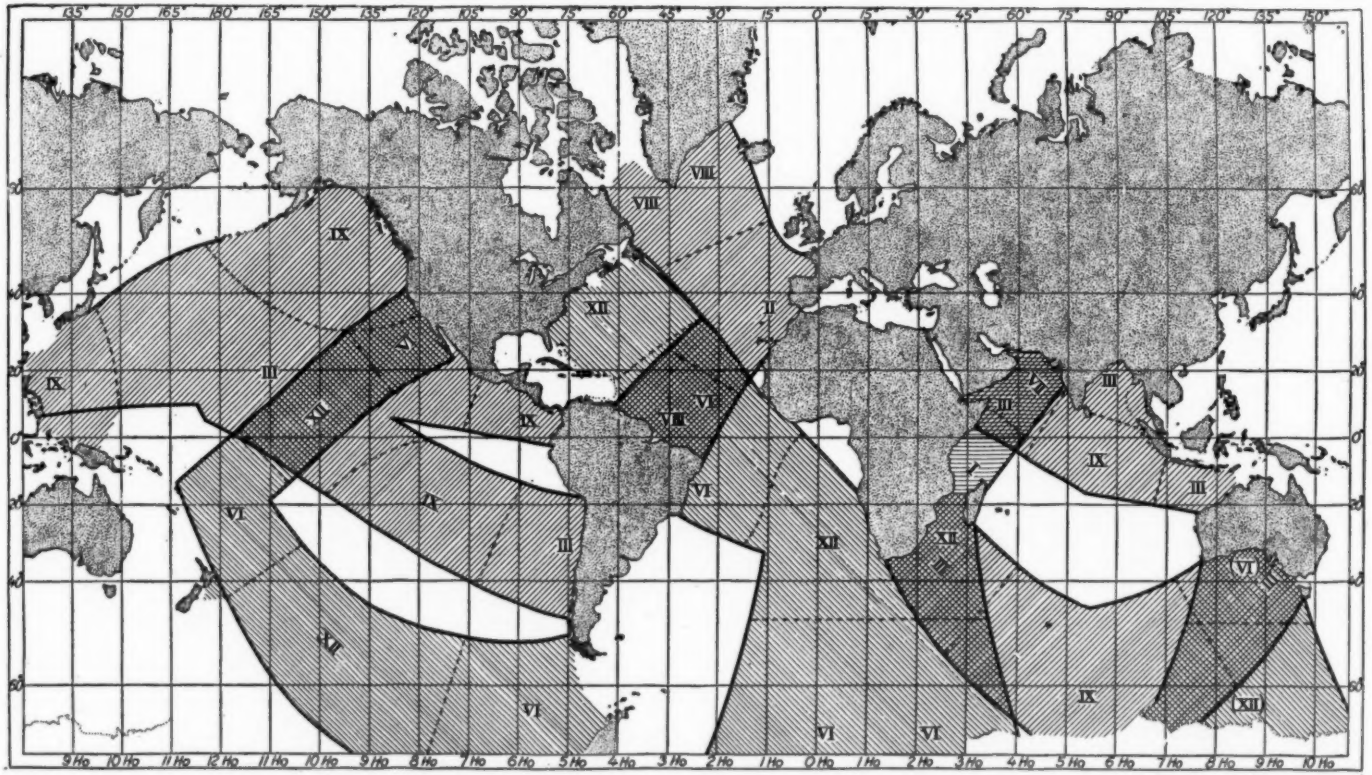


FIG. 4. Systems for the Semi-daily Tides. The shaded portions of this chart represent the regions most concerned in the production of tides, together with landward dependencies which possess tides simultaneous with those of the systems proper. The Roman numerals refer to Greenwich lunar time of high water. The values upon Fig. 4 are nearly those which would result from theoretical considerations. The values upon Figs. 5, 6, 7 and 8 are made to agree with observation as nearly as possible. The Arabic numerals on Figs. 5, 6, 7 and 8 denote mean ranges in feet of the observed semi-daily tide. The Roman numerals are placed upon that side of a cotidal line towards which the wave appears to progress.

The diminution of the mean range of tide in going westward from Portugal indicates the existence of a no-tide point westward from the Azores. Other no-tide points occur in European and American arms of the Atlantic Ocean. The no-tide point between Holland and England was first pointed out by Dr. Whewell and the one in the Adriatic Sea by Dr. Sterneck.

Indian-Ocean Tides

The Indian Ocean contains two strips of water well suited to the production of tides. The first extends from the northwestern coast of Australia to the coast of Somali Land and Arabia, the second, from the southern coast of Australia to the southern coast of Africa and Madagascar—the southern edge of this strip resting upon the Antarctic Continent. The tides of the Bay of Bengal depend upon those generated in the first strip, while the horizontal shading in the area between Madagascar and Hindustan, taken in connection with the tidal hours, indicates that an oscillation exists in this area which depends chiefly upon the rise and fall of the tide at the southern end of Mozambique Channel.

The stationary character of the tide in the Bay of Bengal is shown not only upon the small chart of the world, but also upon the chart of cotidal lines which covers the Indian Ocean (Fig. 6). A vertical section is shown by means of a diagram (Fig. 3).

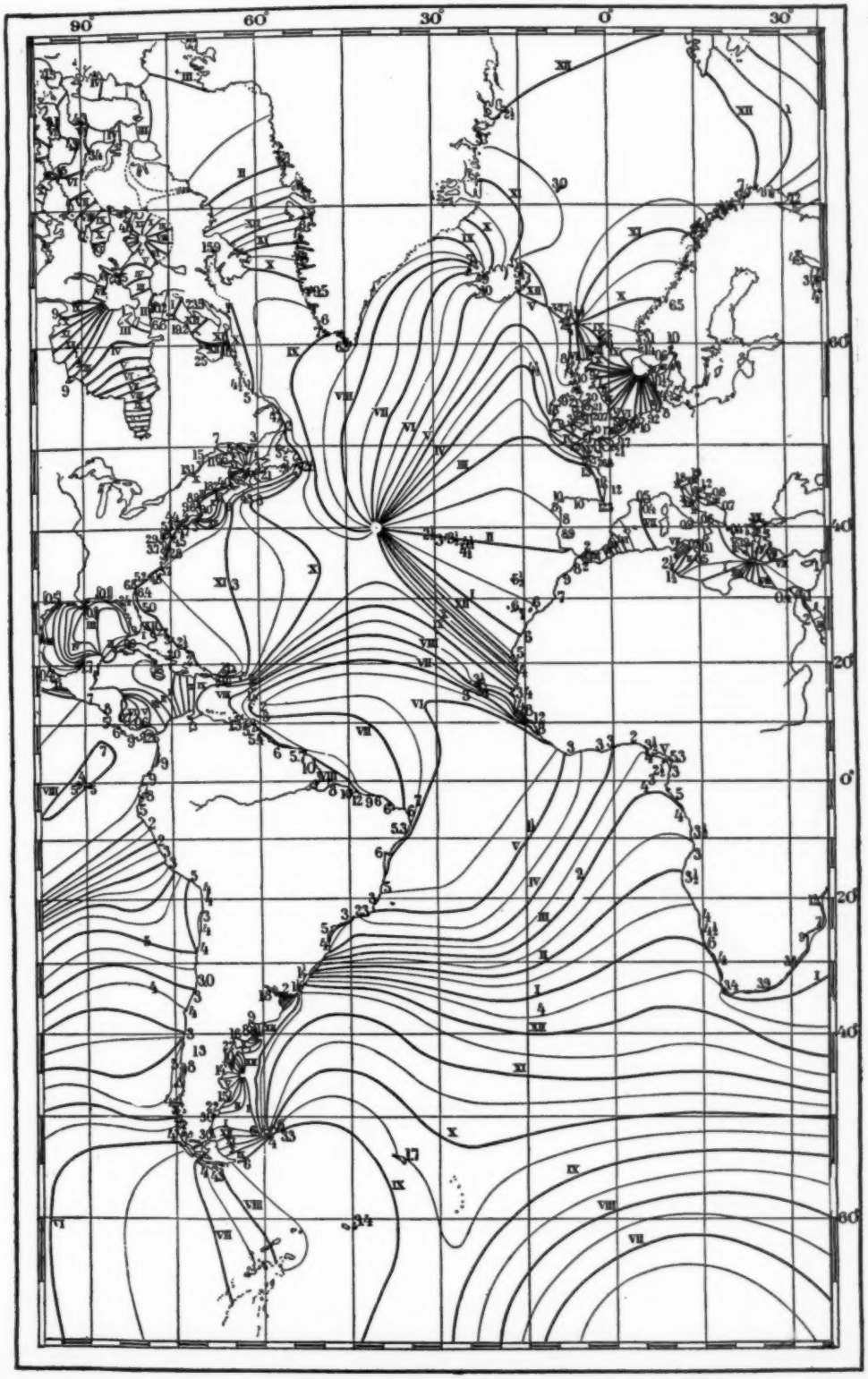
The distance southward from the southern coast of Australia to the Antarctic Continent is less than a half wave-length of the lunar tide. It is more nearly equal to a half wave-length of the solar tide. Consequently the tides due to this oscillation are chiefly solar, and the tidal hours are enclosed in parentheses for the sake of distinction.

Fig. 6 shows that a great diversity of ranges of tide occurs in the Indian Ocean. Between Ceylon and Sumatra the mean range of tide is about one foot, while at the head of the Gulf of Martaban the range is nearly 14 feet. In the mouths of the Ganges the mean range is nearly 10 feet. At the southern extremity of Hindustan Peninsula the mean range of tide is about 1.5 feet while at the head of the Gulf of Cambay it is 23 feet. On the western coast of Madagascar the range of tide is 8 or 10 feet, while at Tamatave, upon the eastern coast, it is 1.5 feet. At Freemantle, near the southwestern corner of Australia, the range of the semidaily tide is 0.4 foot, while at Collier Bay and King Sound on the northwestern coast the mean range of tide is about 24 feet.

Between Madagascar and Hindustan is a no-tide point where the rise and fall of the semidaily tide vanishes.

Pacific-Ocean Tides

The tides in the Pacific Ocean are produced by two systems of oscillations which are distinguished from each other by the two kinds of



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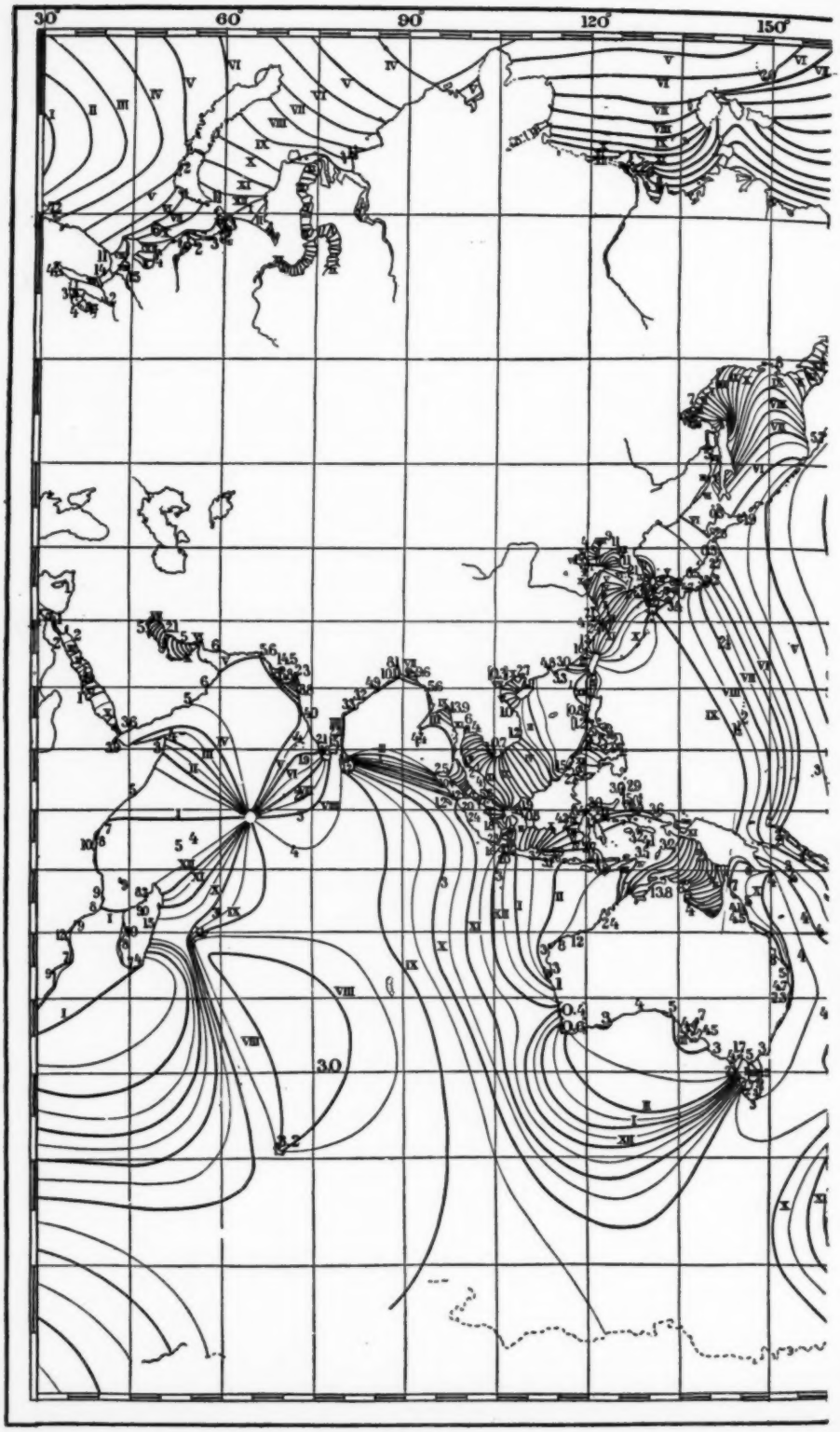


FIG. 6.

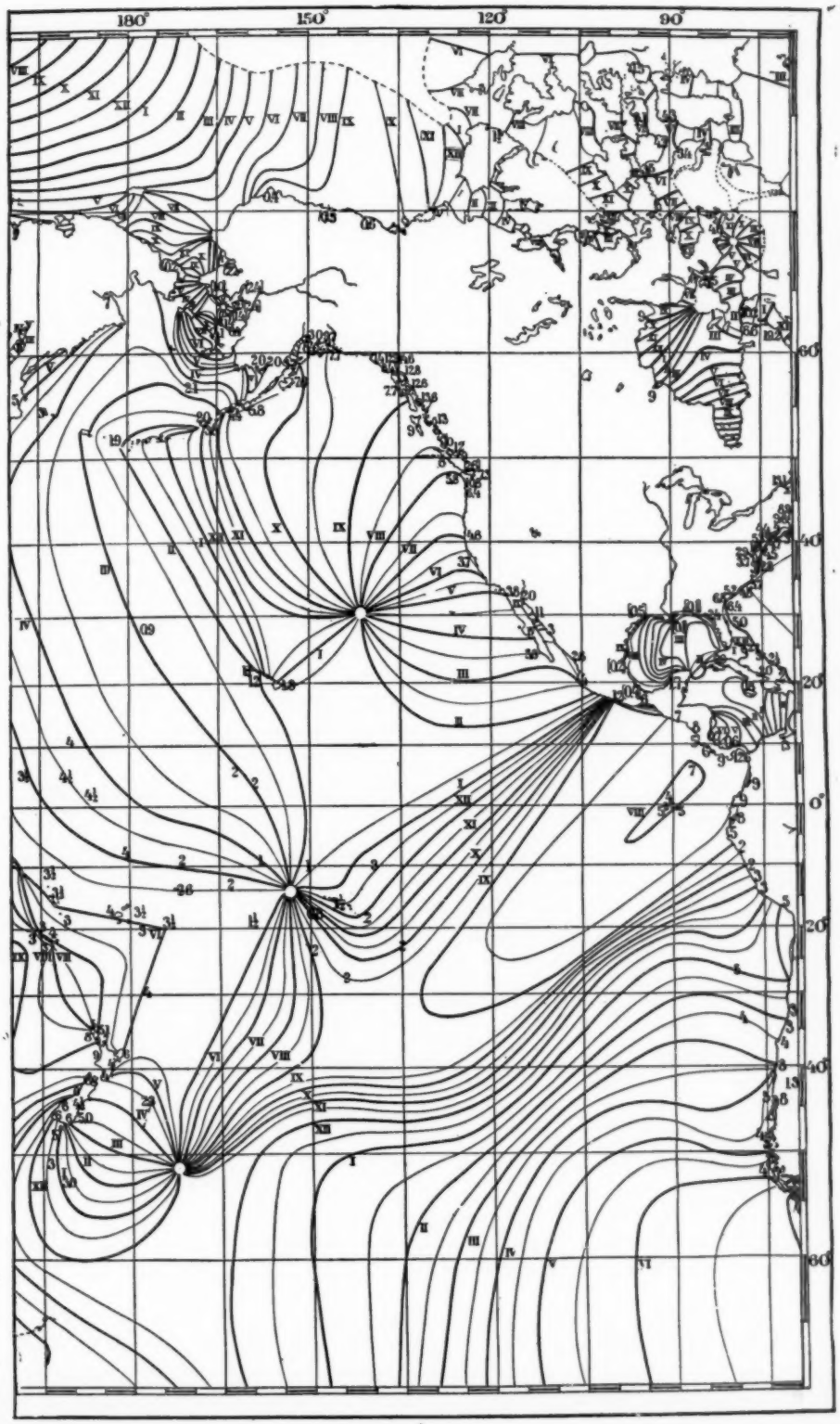
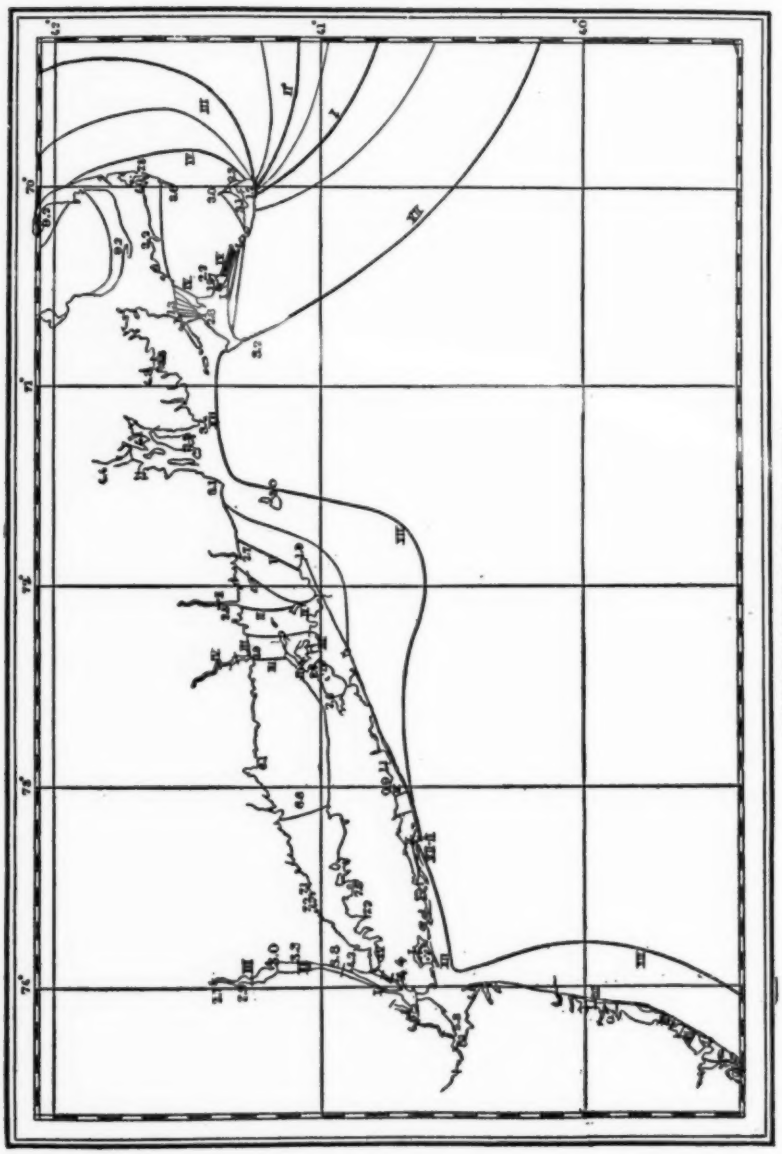


FIG. 7.

shading (Fig. 4). The region occupied by the first comprises a triangular body of water covering the greater portion of the North Pacific Ocean, and also a trapezoidal body extending in a southeasterly direction to the coast of Chile. The nodal line near Acapulco, Mexico, is



Cotidal lines for New York Harbor and approaches.
FIG. 8.

very apparent from observation, as can be seen upon consulting the chart of cotidal lines for the Pacific Ocean (Fig. 7). The same chart shows the stationary character of the oscillation by the fact that at the three angles of this huge triangle—that is, in Panama Bay, the Gulf

of Alaska and off the coast of Luzon—the tide occurs at nearly one and the same time, while the amount of rise and fall is considerable. Also, that for a considerable area around each of these angles, the time of tide changes slowly in going from place to place. The range of tide gradually decreases from the Gulf of Alaska, where it is about eight feet, to the western groups of the Aleutian Islands—the range off Rat Islands being less than two feet.

The South Pacific system embraces an L-shaped region extending from the coast of California and Lower California to the shoals and islands north of New Zealand, thence southeasterly to southern Chile and Graham Land.

Three no-tide points occur in mid-ocean, one occurs in Norton Sound, Alaska, one near either end of the Sea of Japan, and one in the Gulf of Pechili.

Tides at the Isthmus of Panama and Elsewhere

Referring now to the cotidal maps of the world, it appears that the mean range of tide at Panama is 12.6 feet, while at Colon, just across the isthmus, it is only 0.6 foot. That a great difference between the tides at these two points exists was mentioned by Oviedo y Valdez as long ago as 1526, and the question as to the reasons therefor has been frequently raised even up to the present time. Upon consulting the small chart of the world, it will be seen that Panama is situated at one angle of the triangular area where the rise and fall would naturally be greatest.

On the other hand, the tides which enter the Caribbean Sea from the ocean must be small because of the proximity of the nodal line setting out from the Lesser Antilles (Fig. 4). The time and range of the small tide at Colon indicate that it belongs to the equilibrium tides of the Caribbean Sea itself.

Likewise the small tides in the southwestern portion of the Gulf of Mexico are equilibrium tides belonging to the gulf.

The tides in the eastern portion of the Mediterranean are equilibrium tides of that body.

The tides in the Red Sea consist partly of a bodily oscillation of that sea and partly of a progressive wave from the Indian Ocean.

The tides found along the South American coast, from Cape Horn to Rio de la Plata, are derived from the tides of the Pacific Ocean, as is apparent from the chart of cotidal lines for the Atlantic Ocean. The range of tide is about thirty feet at the eastern end of Magellan Strait and less than two feet at Buenos Aires.

Dependent Stationary Wave

It has already been noted that a dependent stationary wave occupies the Bay of Bengal. Such waves are found in the following arms of the

sea: The English Channel; the Irish Sea; the Adriatic Sea; the Gulf of St. Lawrence; the Gulf of Maine, including the Bay of Fundy; Long Island Sound; Bahia Grande; the Gulf of California; the Gulf of Georgia; and Norton Sound. These waves are accompanied by progressive waves, setting inwardly; and the effects of the deflecting force of the earth's rotation upon the moving waters are generally more or less apparent. As a consequence, nodal lines, such as characterize simple stationary waves, are more or less concealed in the bodies of water just mentioned.

Tides in the Vicinity of New York

Turning now to the chart of cotidal lines for New York Harbor and approaches (Fig. 8), several items may be noted:

The tidal hour changes rapidly along the southeastern coast of Nantucket Island. Here the range of tide is small. Over Cape Cod Bay the time of tide is simultaneous, and the mean range exceeds nine feet. Through Muskeget Channel the tidal hour changes rapidly and the currents are hydraulic in character; *i. e.*, the flood and ebb are not oscillatory, but simply flow towards the body of water which is temporarily the lower. A similar remark is approximately true for Vineyard Sound. Over Buzzards Bay the tide is nearly simultaneous, indicating the stationary character of the tide wave. A similar remark is approximately true for Narragansett Bay.

The proposed Cape Cod Ship Canal will connect the waters of Cape Cod Bay at a locality where the average rise and fall of the tide is nearly ten feet with those of Buzzards Bay, where the average range scarcely exceeds four feet. The difference in level due to the tides will suffice to produce in this canal, a tidal current having an ordinary maximum velocity of three knots per hour.

In the eastern portion of Long Island Sound the time of tide changes rapidly and the range of tide is small. Over the greater portion of the Sound the tide is nearly simultaneous; and the mean range exceeds seven feet at the western end. The time and range of tide change rapidly through East River, and the tidal currents are hydraulic and strong. West of the northern end of Blackwells Island, the ordinary maximum velocity is five knots. Before the Hell Gate channel was cleared of reefs and submerged rocks, the currents were a source of much inconvenience and danger to all shipping passing through the East River. The time and range of tide change rapidly in Fire Island Inlet, and the tidal currents are hydraulic and strong. A similar remark is true for Barnegat Inlet. The tide in Raritan Bay consists chiefly of a stationary wave. The tidal currents in Arthur Kill and Kill van Kull are nearly hydraulic. The tide in the Hudson River consists chiefly of a progressive wave.

Attention has been called to these local details for the purpose of showing how varied the tidal phenomena may be within a comparatively limited region, and that detailed cotidal maps can be constructed with accuracy only after tidal observations have been made at a great number of points along the shores and upon the islands included in the area to be represented. The gauging of the tide away from land has seldom been undertaken; but there are indications that in the future such work will be carried out on an extensive scale.

Concluding Remarks

From the cotidal maps of the world, the reader can draw his own conclusions concerning the resemblance between the tides as they must approximately occur in nature and the hypothetical tides progressing westerly around the globe according to the popular conception of to-day and which, as we have seen, existed at the time when the Ptolemaic System held sway over the astronomy of mediæval times. He will find no indications of tide waves having crests coincident with meridians and progressing westward at the rate of fifteen degrees of longitude per lunar hour. He will see that even a general westerly progression of the tide around the globe has no existence in fact.

The dictum of Aristotle, Pliny, Newton and others, that large tides are found in large seas, can be tested by means of these charts. The truth of this is manifest when the tides of the Mediterranean Sea are compared with those of the North Atlantic Ocean, but no such rule applies when the tides of the North Atlantic Ocean are compared with those of the Pacific Ocean and especially with those of the South Pacific Ocean.

The reader may ask, How does it happen that even rude approximations to the tides in nature have been so slow in their development? The answer is, Definite or applicable theories concerning the causes of existing tides were impossible before the depths of the oceans had become generally known. And so, before a few decades ago, tidal theories were developed with reference to certain assumed or hypothetical cases. This remark is no disparagement of the labors of such men as Newton, Laplace and Airy, and which compel the admiration of all persons interested in tidal matters. In fact, the comparative simplicity of the hypotheses upon which their theories were founded, placed tidal work squarely upon a scientific basis and enabled these intellectual giants to press their investigations a long way towards completion.

As to the construction of cotidal lines for the various oceans, it may be said that this implies, not only a rational approximate theory, but also a multitude of carefully-made tidal observations; such observations are, even to-day, either wanting or defective in many portions of the globe despite the efforts of individuals, expeditions, learned societies, institutions and governments.

FACTS CONCERNING THE DETERMINATION AND INHERITANCE OF SEX

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SINCE the time of Aristotle numerous observations have been recorded concerning the phenomenon of sex. Long prior to this period, undoubtedly, men were vexed by such questions as: Why in the same litter of animals are some male and others female? Why in the same brood of chickens do some develop into hens and others into cocks? Why in the same family are some of the children girls and others boys? What determines that one animal or plant shall be male and another female? When does the sex of the organism become unalterably fixed? What is the nature of sex? A great deal of light has been recently thrown upon all these questions. In modern times a solution is being attempted by refined scientific means. Statistical, experimental and cytological methods of research are being employed. The fogs of mystery enshrouding the phenomenon of sex are becoming more and more attenuated and we may confidently hope soon to see them cleared away. Much has lately been discovered that strongly indicates the probable answer to the foregoing questions. Moreover, in their attempts to elucidate the enigmas of sex, men have been actuated as much by a pure scientific motive of love of truth as by the practical bearing of completer knowledge respecting sex-determination on the matter of the control and regulation of sex. The two main problems involved concern the *time when* sex is determined and the *means by which* such determination is established.

Aristotle had noted in the case of pigeons that of two eggs laid in each batch, one generally produced a male and the other a female. He further reported that the first gave rise to the male and the second to the female. Flourens has confirmed this fact for eleven sets of eggs and Cuénot has more recently obtained the same result. What is the meaning of this fact? Aristotle speculated and men are still speculating. When Drelincourt wrote regarding the matter of sex in the eighteenth century he gathered together two hundred and sixty-two theories and hypotheses concerning the nature and cause of sex and declared them all "groundless." Blumenbach subsequently contributed another and reported two hundred and sixty-three worthless theories, having added Drelincourt's to the list. Since then the number of theories not well founded on actual facts has increased to more than five

hundred. The great majority of these are largely unscientific, the result mostly of philosophical speculation or *a priori* opinion. As examples of such it was supposed that an egg from the right ovary gave rise to a male and an egg from the left ovary to a female; that the sex of the offspring was like that of the younger or more superior parent; the exact opposite of the latter, that the sex was that of the weaker or older parent; or that the younger or more vigorous parent determined the opposite sex in the offspring; and many others involving equally off-hand assumptions. That the sex of the offspring is that of the weaker parent has been recently advocated again and statistically apparently well supported by Dr. Romme, a well-known physiologist of London. In further support of his theory he cites the fact that among barbarous nations continually at war there is always a preponderance of boys over girls.

Professor Schenck's famous sex-theory is in essence the same. He proposes to increase the physical vigor and the number of the red blood corpuscles in a person when it is the wish to beget a child of the opposite sex. Renewed interest has been aroused in this theory, due to Professor Schenck's connection with the royal family of Russia, where he put his principle to the test with an apparently successful result when the Czarina gave birth to the desired son. But Professor Simon Newcomb, as the result of a very extensive statistical investigation, concludes that "it seems in the highest degree unlikely that there is any way by which a parent can affect the sex of his or her offspring."

Within the last decade students of the problem of sex have become very generally agreed that sex is inherited. In other words, they believe that the same mechanism that provides that an offspring shall have one or the other of a pair of contrasting characters represented in the two parents (a long sharp nose or a short stubby nose, for example) provides also that the animal shall have either the sex of the mother or that of the father. The problem of sex seems to be part and parcel with the general problem of inheritance. Furthermore, characters of the parents are believed to be inherited by the offspring according to Mendelian principles. And it can be shown, as was done by Dr. Castle, of Harvard University, in 1903, that sex may be regarded as the result of a Mendelian segregation, dominance and inheritance of sexual characters. And now it becomes incumbent to explain Mendelian inheritance before continuing the discussion of the problem of sex, seeing that sex appears to be inherited in Mendelian fashion.

Mendelism is the term employed to designate a set of phenomena that appear when animals or plants with sharply contrasting characters (white flower petals and colored petals; gray fur and white fur; short stature and long stature; sagacity and stupidity; etc.) are crossed. The principles included under the term Mendelism were first discovered

by Gregor Mendel, abbot of Brünn, in 1866. Since then our knowledge of Mendelian inheritance has been greatly extended through the researches notably of Professor de Vries, of Amsterdam; Professor Bateson and Professor Punnett, of Cambridge University, England; Professor Cuénot, of Paris; Professor Castle, of Harvard University; Dr. Davenport, of the Station of Experimental Evolution of the Carnegie Institution at Cold Spring Harbor, Long Island, and Professor Morgan, of Columbia University. For the purpose of elucidating this subject in respect to its essential principles and its peculiar nomenclature we will take the simple case of two varieties of pea, one with seed colored yellow and the other with seed colored green. These are said to be "pure" in the sense that from green seed-bearing individuals when interbred only green seed-bearing plants will arise, and from yellow peas only yellow seed-bearing plants. In order that plants or animals may be successfully crossed it is requisite that they be closely related species or varieties.

Mendel found at the beginning of his work that when a cross is made between two such varieties of peas, the first succeeding generation yields peas that are all colored yellow. When flowers from plants of the latter are self-pollinated, *i. e.*, crossed with their own kind, there result peas of two kinds, yellow and green, and the proportion of such seed is three of the former to one of the latter. This means that the yellow color is "dominant" over the green color, which is said to be "recessive." Mendel further discovered that when the green recessives were self-pollinated their seed always produced only green seed-bearing plants. Such were called "pure recessives" or "extracted recessives." He found also that among the 75 per cent. of yellow seed 25 per cent. always bred true, *i. e.*, they gave rise to only yellow seed-bearing plants. Such were designated "pure" or "extracted dominants." But the remaining 50 per cent. on self-fertilization again yielded peas in the proportion of 75 per cent. yellows to 25 per cent. pure recessive greens. The Mendelian proportion then in the case where a single set of contrasting characters ("unit characters" or pair of "allelomorphs") are crossed is 25 per cent. pure dominants (yellow in color); 50 per cent. color hybrids (also yellow in color, since yellow dominates over green); and 25 per cent. pure recessives (green in color).

Mendel explained the foregoing facts on the assumption that during the process of maturation, when the unripe cells divide each into four mature germ-cells, eggs or pollen grains (ova or spermatozoa in animals), the carriers of the qualities yellow and green are segregated into different cells. In other words, no eggs or pollen grains (sperms) carry both characters, but only one or the other character. Accordingly, among the eggs 50 per cent. carry the quality yellow and 50 per cent. carry the quality green; among the pollen grains 50 per cent. again

carry only the yellow color and 50 per cent. the green. At fertilization eggs and pollen grains meet fortuitously and according to the laws of chance there are twice as many possibilities that an egg with a green color-determinant (G) shall meet a pollen grain with a yellow color-determinant (Y), and *vice versa,* as that an egg with a green determinant shall meet a pollen grain with a green determinant, or that an egg with a yellow determinant shall meet a pollen grain with a yellow determinant. Hence the combinations produced may be expressed thus: 1YY: 2YG: 1GG. Among the seed 50 per cent. are hybrids in respect to color, but since the yellow color dominates over the green all appear yellow, giving a total of 75 per cent. yellow peas and 25 per cent. green peas.

When pure strains of sweet peas with white flowers are crossed with pure-bred peas with red flowers similar results follow. All the plants of the first generation bear red flowers, showing the dominance of red color over white color. When these are interbred the plants of the second generation split up in the proportion of 75 per cent. red-flower-bearing to 25 per cent. white-flower-bearing; or 25 per cent. will be red pure dominants, 50 per cent. red hybrids and 25 per cent. white pure recessives. Also when white mice (albinos) are crossed with gray mice (or pigmented mice) the first generation are all gray, when the latter are bred among themselves the second generation includes albinos and gray individuals in the proportion of 1 pure gray: 2 gray hybrids: 1 pure white.

In applying Mendelian principles to sex, maleness and femaleness are regarded as unit characters and during the maturation of the germ-cells the carriers (chromosomal elements) of the male and female qualities are believed to be segregated in different cells, both ova and spermatozoa, so that one half of the ova contain the male-determining factor and the other half the female; and likewise the spermatozoa. The result of a fortuitous intermingling of ova and sperm, according to strict Mendelian laws, should produce male and female individuals in the proportion of 3:1 or the reverse. Suppose femaleness dominated, then there would be 75 females in every 100 of population or of any particular species. No such disproportion of sexes obtains. In fact, barring a few exceptions which may be explained as adaptations or as the result of a selective mortality, all species are approximately equally divided into two classes with respect to sex. Further assumptions must be made and pure Mendelism modified. The obvious and necessary assumptions are that there are no individuals pure in sex; all are hybrids; and the sex that the organism attains is the result of a struggle between the mingled male and female tendencies and the dominance, now of one tendency, now of the other. The dominance may be due, as Dr. Thomson, of the University of Aberdeen, suggests, to slight

metabolic fluctuations, now in favor of maleness (katabolic), now in favor of femaleness (anabolic), the net result being an approximately equal proportion of males to females. In other words, there must be selective fertilization, that is, a female ovum must be fertilized by a male sperm, and *vice versa*. The various assumptions made are not pure speculations, but rest upon many facts. Some animals do possess two kinds of eggs, of which one (the larger) develops into females and the other kind (the smaller) into males; there are many instances of selective fertilization; and many animals do produce two kinds of spermatozoa.

If there is only one kind of egg, as Correns suggests—as may well be the case, since of the four potential ova, three (the polar bodies) degenerate during maturation and only one becomes capable of fertilization—and two kinds of spermatozoa, the explanation of sex becomes very much simpler. One sex (female) must then be pure in respect to sex (a homozygote) and the other must be a sex-hybrid (heterozygote). If the egg is female in tendency, in order that there should appear 50 per cent. males, maleness must dominate over femaleness. In any case, an interpretation of the facts involves the application of some phase of Mendelism. As will appear farther on, the case of the honey-bee, ants and plant-lice offer serious obstacles to the universal application of Correns's interpretation, and even of the whole Mendelian scheme.

Within the last decade three main positions have been advocated by various investigators in regard to the cause of sex. The position held by Beard and his school is to the effect that there are two kinds of eggs, male and female, and one kind of spermatozoa; and that sex is determined exclusively by the egg, the spermatozoon having no rôle in sex production. This position can be supported by various facts. A certain worm (*Dinophilus apatris*) carefully studied by Korschelt, is known to produce two kinds of eggs, large and small, the former developing into females, the latter into males. Of course it might be urged that in consequence of selective fertilization only the small eggs are impregnated by a male-producing spermatozoan and the large eggs by a female-producing, and an entirely different interpretation of the facts would be necessitated. But in the case of *Hydatina senta*, a rotifer or "wheel animalcule," where large and small eggs are also laid, the former without fertilization develop into females and the latter into males. However, both kinds of females, the large-egg-laying kind and the small-egg-laying kind, came originally from fertilized eggs, and it may be that a difference in metabolic activity of the several females kept the eggs of the one small and allowed those of another to grow large and so gave the victory to the female determinant in the well-nourished egg. This assumption is supported by the fact that the amount of nourishment taken by the young female between

the time of emergence from the egg and deposition of her first egg determines which kind of egg she shall subsequently produce. The well-nourished females produce female eggs, the poorly nourished produce male eggs. Sex, however, is determined while the ovum is still in the ovary. When the eggs have once been formed no subsequent change of food or temperature can alter the kind of eggs that are produced. *Phylloxera vitifola,* the plant louse that lives on the roots of the grapevine, also produces large and small eggs, developing parthenogenetically (without fertilization) into females and males, respectively.

The second position is that taken by Strasburger, Castle, Wilson and others who have derived their facts largely from the group of insects. These investigators are inclined to believe that there are two kinds of eggs as there are two kinds of spermatozoa, and that sex is the outcome of an interplay or struggle of the sex determinants of these elements and the dominance of one or the other sex. According to these biologists all animals are sex-hybrids; either sex is potentially present originally, but by reason of the dominance of one or the other sex-determinant the particular sex becomes patent and makes the animal definitively male or female. Dominance may be due, in many cases, as is indicated by some of the Hemiptera, to the presence of one or several extra and specific chromosomes—"idiochromosomes," "X-element" (Wilson). According to this view fertilization is selective, *i. e.,* a female egg is fertilized only by a male sperm, and *vice versa.* There are many observations and ascertained facts to support this position.

The case of the large "walking-stick" insect (*Aplopus mayeri*) or "devil's riding horse" of Loggerhead Key, Dry Tortugas, Florida, which I studied in 1907, illustrates the position under discussion. Similar facts had been reported previously for many insects by various American cytologists, notably Professor McClung, of the University of Kansas; Professor Montgomery, of the University of Pennsylvania, and Professor E. B. Wilson, of Columbia University. *Aplopus mayeri* (named after Dr. A. G. Mayer, director of the Biological Laboratory of the Carnegie Institution of Washington at Dry Tortugas, Florida) produces two kinds of spermatozoa differing in the number of chromosomes (rod-like bodies supposed to be the vehicles of the hereditary qualities) that the two classes possess. One half of the spermatozoa hold 17 chromosomes and the other half 18, the additional one being large and V-shaped (called by McClung the "accessory chromosome"). The somatic cells of the male contain 35 chromosomes, the somatic cells of the female, 36 chromosomes. When the eggs mature, the 36 chromosomes are reduced, by fusion in pairs and a subsequent double division, to 18 chromosomes. Now at fertilization when an egg of 18 chromosomes unites with a spermatozoan of 18 chromosomes an organism whose cells contain 36 chromosomes results, and this is a female;

when the other combination occurs, 18 chromosomes from egg and 17 chromosomes from sperm, an organism results that has only 35 chromosomes, and this is a male. It seems, therefore, as if the accessory chromosome was a sex-determinant in some sense—probably only in the sense of a visible accompaniment of some hidden underlying physiological cause of sex—perhaps as the carrier of a specific enzyme or "hormone."

To bring these facts into line with Mendelian principles it becomes necessary to postulate (1) two kinds of eggs, just as there are two kinds of spermatozoa, (2) selective fertilization, and (3) dominance of femaleness, and the observed facts can be explained. If the accessory chromosome is a sex-determinant, then when an egg is fertilized by a sperm lacking this element, the egg itself must carry the factor that determines that the sex of the resulting organism of 35 chromosomes shall be a male. In the event of the other possible combination the egg selected must have been one carrying the female determinant and, since the accessory chromosome is a male-determinant and the union of the two produces a sex-hybrid, femaleness must dominate in order to yield a female organism of 36 chromosomes.

The most recent position is that of Dr. Correns, professor of botany in the University of Leipsig, to the effect that there is only one kind of egg (always female) and two kinds of spermatozoa. He has brought forth facts to amply support this view in flowering plants. He shows that the spermatozoa determine the sex and that the time of this determination is the instant of fertilization. Correns attempts to bring the second position above mentioned into harmony with his own, and the facts upon which Beard's position is based are given a reasonable interpretation. We shall consider these various positions from Correns's standpoint, and will note how he disposes of the obstacles above referred to.

There are now known about one hundred cases, mostly among the air-breathing arthropods, where there is a dimorphism of spermatozoa. But if fertilization determines the sex, what about such cases where eggs develop without fertilization, as in the drone honey-bee, ants and plant lice (aphids and phylloxerans)? These several examples until recently had been serious stumbling-blocks to the theory that sex is dependent on a dimorphism of spermatozoa. Nor is the matter yet as clear as we could wish it to be. All the fertilized eggs of the honey-bee develop into females (workers or queens, depending upon the kind and amount of food they receive), the unfertilized eggs develop into males or drones. Meves has recently found that while the drone honey-bee produces two kinds of spermatozoa, one set, the male-producing, degenerates and becomes non-functional. Hence all fertilized eggs must develop into females. The facts become intelligible if we

assume that all the eggs possess a predominating male tendency. There appears to be justification for this assumption since two polar bodies are formed and a reduction division takes place which may be thought of as partially eliminating the female tendency. Due to the preponderance of female elements, fertilized eggs become females. Unfertilized eggs become males, since the male tendency is undominated.

Aphids produce brood after brood of parthenogenetic females while food and climatic conditions remain favorable. When environmental conditions become adverse both males and females appear between whom eggs are fertilized, which as "winter eggs" resist the elements until the following summer, when they develop into parthenogenetic females. These facts may be thus explained: the original ancestor (stem-mother) of a parthenogenetic series arises from a fertilized egg; the eggs of the parthenogenetic females are all hybrids as to sex. No reduction is thought to take place when the single polar-body is formed. When conditions are favorable, metabolic activities give the ascendency to the female elements; when these become adverse, the male element gains the ascendency in some of the eggs. When males and females appear the sex determinants are segregated in the ova and spermatozoa in equal proportions in each. During maturation in the male aphid, however, Dr. N. M. Stevens, of Bryn Mawr College, and also Dr. W. B. von Baehr, of Germany, have discovered that half the sperm degenerate (these lack the accessory chromosome) and that these are male-producing kind. Hence, since only female-producing sperm remain, all fertilized eggs (sex-hybrids) must develop into females.

In the case of *Phylloxera,* where many generations of wingless parthenogenetic females appear while environmental conditions remain favorable, and when these become adverse, give way to winged males and females, Dr. T. H. Morgan has discovered a similar degeneration of the male-producing spermatozoa and the loss of a chromosome in the parthenogenetic males. In these cases we must assume that the eggs are intrinsically different (male and female), as they really appear externally, or else, as Correns proposes, that the eggs are potentially male and that in the fertilized egg where both sex tendencies are present femaleness dominates when environmental conditions are favorable to constructive metabolism. But some mechanism or condition must remain whereby an apparently homozygous male may produce spermatozoa bearing a female tendency. It is by no means proved that the whole quota of female tendencies (elements) is eliminated at maturation. The male and female (paternal and maternal) chromosomes are probably promiscuously arranged on the spindle. The persistence of chromosomes bearing female characters may supply the demands for the production of female-producing spermatozoa.

The sex of the offspring then appears to be the result of the inter-

action of two factors, both unknown quantities. By the union of an egg and a sperm an organism is produced which has a certain sex. If we let X represent the unknown sex tendency of the ova, and Y the unknown sex tendency of the spermatozoon, then we may state the process of sex production thus: X + Y = sex of offspring. If we could discover the value of X or Y we could solve the equation and discover the secret of sex. Correns, as the result of experimentation with certain flowering plants since 1900, has found the value of X in these particular forms and has thus contributed invaluable facts for the reinterpretation of former observations and for the formulation of a wider generalization regarding sex phenomena.

Many facts are known which leave little doubt that in most animals sex is absolutely fixed in the fertilized ovum. A real exception is the case of the frog, where the embryo or even the larval tadpole is hermaphroditic, *i. e.*, it contains both ovaries and testes. In a later stage of development one or the other of these pairs of organs degenerates when the frog becomes a definitive male or a definitive female.

In the human species twins are frequently of the same sex, either male or female. Such twins are known as "identical twins" when enveloped in a common chorion or fœtal membrane. They are the result of an independent development of accidentally separated cells at the two-cell stage of development. Double monsters likewise are always of the same sex. "Ordinary twins" are as frequently of opposite sex as of the same sex. In this case each fœtus is enveloped in its own chorionic membrane. Such twins are the result of the synchronous development of two ova simultaneously successfully fertilized. These facts show that sex is already determined in the fertilized egg and before the first segmentation. Similar evidence is contributed by Jehring, who studied poly-embryony in a species of armadillo (*Tatusa hybrida*) found in Paraguay. Here as many as eight offspring appear at a single birth. Jehring reports that all eight fetuses are enclosed in a common fetal envelope. Hence the eight offspring must result from the development of the products of division as the eight-cell stage of segmentation. Since the offspring are all of the same sex, sex must have been already determined in the fertilized egg prior to the first cleavage. Again, Professor Silvestri, of Naples, has quite recently contributed new facts which lead to the same positive conclusion. He has discovered that *Litomastix,* a kind of bee (Chalcidæ), lays its eggs in the egg of a moth, *Plusia.* As the latter develops into a larval caterpillar, the egg of *Litomastix* segments into a chain of many eggs, each of which gives rise to an embryo bee. The caterpillar may contain a hundred such embryos and they are all of the same sex—female if the egg was fertilized; male if unfertilized. Sex must have been already fixed in the fertilized egg. But this is an

entirely different matter from the position that Correns takes that sex is fixed at the time of fertilization and determined by the spermatozoa.

Correns made his experiments with two species of Cucurbitaceæ, the family to which our pumpkin and squash belong, growing wild in central Europe. These two species are *Bryonia alba* and *Bryonia dioica*. The former is the plant which supplies the root employed in pharmacology for the treatment of dropsy. The especial value of these species for experiments relative to the problem of sex, lies in the fact that the former is hermaphroditic or monœcious, *i. e.*, mature male and female flowers appear on the same plant; and the latter is diecious, *i. e.*, male and female flowers appear on different plants. These two species can be crossed in either direction. Correns made three sets of experiments, the results of which have led him to a unique and simple explanation of the cause of sex, in the light of which former theories must undoubtedly be more or less extensively modified. Correns first crossed *Bryonia dioica* with *Bryonia alba,* using the eggs of the former and the pollen grains of the latter. Sterile hybrid-offspring appeared from the cross and they were all *females.* Correns explains that since germ-cells of the hermaphrodite forms carry only hermaphrodite determinants, the male gametes (pollen grains) can have had no influence on the sex of the offspring of this cross. In other words, hermaphroditism is recessive to dieciousness. And since the offspring were all female, all the eggs of *Bryonia dioica* must have had female tendencies.

Correns next pollinated the pistils of *Bryonia dioica* with the pollen of the same species. Forty-one pure *dioica* offspring were obtained from this cross, twenty-one of which were female and twenty male, or in round numbers each sex appeared in 50 per cent. of the individuals. Since the eggs were all female, as shown by the first experiment, this result must mean that the pollen grains determine the sex and that they must be of two kinds, male and female in tendency, and approximately equal in number. It must also mean that the male tendency dominated over the female, else no males could have appeared.

In a third set of experiments the pistils of *Bryonia alba* were pollinated by *Bryonia dioica.* The offspring in this case were sterile hybrids, and of the seventy-six which came to maturity thirty-eight were male and thirty-eight female. This again shows that hermaphroditism is recessive to dieciousness since no hermaphrodites appeared. It shows also again that there must be two kinds of male gametes with male and female tendencies, respectively, of equal number, and that they determine the sex. It shows, moreover, that sex is determined at the time of fertilization, for before that instant all the female gametes (ovules) had the tendency to develop into hermaphrodite forms. It appears also in the light of this experiment that hermaphroditism and

dieciousness must be regarded as unit characters, since they behave in crossing according to Mendelian laws. Hermaphroditism probably has its chromosome determinant as also dieciousness, hence the cytological study of the germ cells of hermaphrodite forms will hardly supply the clue to the cause of sex as it was until recently believed to do.

In those insects where there is a dimorphism of spermatozoa, consisting in the presence of an accessory chromosome in one half of the gametes, no obvious difference appears among the eggs. There are no real grounds for a division of the ova into those with male character and those with female character. In the light of Correns's recent observations, the eggs had better all be regarded as possessing the same sex tendency, and this probably female in nature. The spermatozoon with the accessory chromosome need then only be thought of as possessing the female tendency, and the one that lacks it, as possessing the male tendency, and the facts are brought into line with the results of Correns and admit of the same interpretation. In the case where large and small eggs are produced, as by *Dinophilus apatris*, it is conceivable that there is selective fertilization, *i. e.*, while both types of egg may be female in tendency, only the larger admit of fertilization by a female-producing spermatozoon.

The present status of the case concerning the determination of sex, as well supported for a large class of plants and animals, appears to be that sex is determined by the spermatozoa (or pollen grains)—which are male and female in the proportion of 1:1—and at the instant of fertilization. But surely it would be the utmost folly to hold on the basis of so comparatively few facts, that this explanation applies universally. Nature arrives at similar ends by devious and divers ways and it is not inconceivable that sex has been attained by several paths, and is now determined in different modes and at different times in the different groups of animals and plants.

JOSIAH WILLARD GIBBS AND HIS RELATION TO MODERN SCIENCE. II

By FIELDING H. GARRISON, M.D.,

ASSISTANT LIBRARIAN, ARMY MEDICAL LIBRARY, WASHINGTON, D. C.

The Thermodynamic Potentials.[56]—In 1869 the physicist F. Massieu communicated to the French Academy of Sciences the discovery of two algebraic functions from which all the thermodynamic properties of a fluid may be derived.[57] These "fonctions characteristiques" of Massieu contain in latent form two of the four relations which Gibbs derived independently from his general thermodynamic equation and which have since been variously interpreted as the fundamental functions or thermodynamic potentials of heterogeneous chemical systems. Mathematically they are simplifications which dispense with the necessity of endless transformations of equations and formulæ, evolving, as Bryan says, "order out of chaos."[58] As the foundations of thermodynamics are its two laws, so the potentials may be regarded as the coping stones of the edifice, and all recent progress in the science, as in the physics of gas mixtures, osmosis, elastic solids or electrolysis has been made with their aid. The four potentials are now interpreted as the "free energy" (ψ) and the "modified available energy" or total thermodynamic potential (ζ) for constant temperature, and the intrinsic energy (ϵ) and heat function (χ) for constant entropy.[59] Of these the first two are the most important, being the analogues of the Newtonian or gravitational potentials (potential energies) of mechanical systems, generalized, as Larmor says, "so as to include the temperature" and connoting thermal effects,[60] just as the Maxwellian potentials connote effects of electromotive force. They

[56] *Tr. Connect. Acad.*, III., 144–52.

[57] "J'appelle cette fonction *fonction caractéristique* du corps: en effet, lorsqu'elle est connue, on peut en tirer toutes les propriétés du corps que l'on considère dans la thermodynamique . . . Je rapellerai d'ailleurs qu'une fois la fonction caractéristique d'un corps déterminée, la théorie thermodynamique de ce corps est faite." F. Massieu, *Compt. rend. Acad. d. sc.*, Paris, 1869, LXIX., 859, 1058.

[58] Bryan, "Thermodynamics," Leipzig, 1907, 109.

[59] If ϵ, t, η, p and v represent the energy, temperature, entropy, pressure and volume of a chemical or thermodynamic system, its thermodynamic potentials will be the *intrinsic energy* ϵ obtained by integrating Gibbs's fundamental equation, the *free energy* $\psi = \epsilon - t\eta$, the *total thermodynamic potential* or "modified" available energy $\zeta = \epsilon - t\eta + pv$ and the *heat function* $\chi = \epsilon + pv$.

[60] Larmor, "Encycl. Britan.," 10th ed., XXVIII., 167.

represent that part of the energy of a system which is due to changes in its mass or structure rather than to thermal or molecular changes, and so can take part freely in physico-chemical transformations. For this reason the potential ψ, which is the difference between the total energy of a system and its bound (molecular) energy, was called the "free energy" of the system by Helmholtz, who rediscovered the principle independently, not knowing that Gibbs had forestalled his labors by at least six years. In lecturing on the subject during the later period of his life, Helmholtz, with his usual breadth of spirit, was inclined to assign complete priority to his predecessor,[61] while both Gibbs and Helmholtz have acknowledged their indebtedness to Massieu.[62]

Criteria of Equilibrium and Stability.—Gibbs's conditions for the complete equilibrium of an isolated homogeneous chemical substance are that its pressure, temperature and the chemical potentials of its components should be constant throughout the mass, since changes of pressure and temperature disturb mechanical and thermal equilibrium, while difference of potentials destroys stability and precipitates chemical change. For an isolated heterogeneous system, as an enclosed liquid and a gas in contact, the following maxima and minima are criteria of complete equilibrium: The system must have and maintain the greatest entropy consistent with constant energy; or for adiabatic systems (at constant entropy), the intrinsic energy (ϵ) or heat function (χ) should have minimum values for constant volume or pressure, respectively, but for isothermal systems (at constant temperature) the free energy potential (ψ) or the thermodynamic potential (ζ) should have minimum values for constant volume or pressure. Any deviation from these maxima or minima will again disturb equilibrium and produce changes of physical or chemical state. The essential feature of spontaneous chemical change is, then, either constant increase of entropy in self-contained or adiabatic systems or a corresponding decrease of free (mechanically available) energy in systems at uniform

[61] "Deshalb hat Gibbs, der auch diese Form der Darstellung zuerst fand, die Function *A* das isotherme Potential genannt." Helmholtz, "Vorles. über theoret. Physik," Leipzig, 1903, VI., 269. See, also, the lecture in his biography by L. Koenigsberger, Braunschweig, 1903, II., 369: "In diesem Sinne hat Herr Gibbs die Grösse F. das isotherme Potential des Körpersystems genannt, ich selbst habe dafür den Namen der freien Energie vorgeschlagen, weil dieselbe Arbeitsäquivalente darstellt, deren Ueberführung in andere Formen der Energie nicht denselben Einschränkungen unterliegt wie die der Wärme." For Lord Kelvin's relation to the discovery of the free energy potential see *Proc. Roy. Soc. Lond.*, 1908, LXXXI., No. A 543, pp. xlvi–xlvii.

[62] "M. Massieu appears to have been the first to solve the problem of representing all the properties of a body of invariable composition which are concerned in reversible processes by means of a single function." Gibbs, *Am. J. Sc.*, 1878, 3. s., XVI., foot-note to p. 445.

temperature, or in Lord Kelvin's phrase, a general dissipation of energy in all irreversible phenomena. For each potential, with appropriate choice of coordinates, a solid model or relief map can be constructed, upon which the different minima of the potentials appear as depressions in the landscape. When the lowest depression or minimum has been reached, complete and permanent equilibrium is attained, and we have what Gibbs calls a "phase of dissipated energy," at which, as in a bar of metal or a block of granite, no further spontaneous changes of physical state are possible so long as the system remains isolated from external forces. In connection with his discussion of equilibrium we may note Gibbs's forethought in extending his equations to n dimensions, since for more than three components a three-dimensional model no longer suffices; his early introduction of the time element into the discussion of chemical reactions[63] and his pages on "passive resistance to change,"[64] which should be read by every chemist, since they are of the essence of his subject, especially in regard to carbon compounds or colloidal substances. In applying dynamic principles to chemical phenomena Gibbs, and after him Helmholtz, thought decrease of free energy at uniform temperature to be the most important condition for equilibrium, since it measures the actual work done and is thus the "force function" of mechanics with reversed sign.[65] The electromotive force of a reversible galvanic cell turns out to be identical with the free energy of chemical decomposition in the cell,[66] and in the field of biology free energy is of equal importance, for relative uniformity of temperature is as common in living processes as in the laboratory. Well did Boltzmann say that "the struggle for existence of living matter is a war for free energy," for when the free energy of a living body becomes a minimum its death is at hand.

The Phase Rule.[67]—Any aspect of a chemical substance which is homogeneous in regard to physical state and percentage composition has been called by Gibbs a *phase* of the substance, the components of a phase being its constituents of independently variable concentration. The phase rule asserts that a homogeneous substance having n components is capable of only $n + 1$ independent phases, while a heterogeneous system of r coexistent phases, each of which has n independ-

[63] Gibbs, *loc. cit.*, 113.

[64] *Ibid.*, 111–3.

[65] See Gibbs, *Am. J. Sc.*, 1878, 3. s., XVI., 442. "The transition from the systems considered in ordinary mechanics to thermodynamic systems is most naturally made by this formula . . . the mechanical properties of a thermodynamic system maintained at constant temperature being such as might be imagined to belong to a purely mechanical system, and admitting of representation by a force function."

[66] Gibbs, *Tr. Connect. Acad.*, III., 520.

[67] *Ibid.*, 152–6.

ently variable components, is capable of $n + 2 - r$ degrees of freedom or variations in phase, of which not more than $n + 2$ can coexist at the same pressure and temperature. Such systems, in Trevor's nomenclature, are spoken of as invariant, monovariant, divariant, etc., according to the number of possible variations of state. Thus water (H_2O) has three independent phases, ice, liquid and steam, and is invariant, the three phases being in equilibrium at only one pressure and temperature, called the triple point, where the steam-line, ice-line and hoar-frost line meet. But when calcium carbonate ($CaCO_3$), calcium oxide (CaO) and carbon dioxide (CO_2) are in equilibrium, we have three coexistent phases formed of two components (CaO, CO_2) and the system is monovariant. By this rule the chemist is able to predict the number of modifications of which a chemical substance is capable from observation of its physical properties alone, or the number of substances in a mixture from notation of the number of phases possible, or the strength of a saturated solution from its temperature and pressure. Many different proofs of the phase rule have been given by mathematicians and physicists from varied and independent points of view,[68] and there is every indication that it is a complete and accurate statement of a general chemical law. Its practical significance remained for a long time undiscovered until the Dutch chemist Van der Waals took it up, and when, in 1884–6, his colleague, Bakhuis Roozeboom, found himself unable to explain certain puzzling phenomena connected with the equilibrium of gaseous hydrates and of double ammonium salts, van der Waals was able to direct his attention to Gibbs's theorem and showed him, by working out a special case, how thermodynamic methods might be applied to practical chemistry.[69] From that time on Roozeboom became the devoted champion of the phase rule, which he compares to the ground plan of a gigantic building in which all the collected phenomena of chemical equilibrium can be stored in a convenient and comprehensive manner. "This structure," he adds with pride, "has since been completed, almost exclusively by the work of the laboratories of Leyden and Amsterdam."[70] In fact, the investigations of Roozeboom and van't Hoff upon double salts, solid solutions and metals are among the most brilliant results of modern chemistry. It is in connection with the graphic study of chemico-physical changes by the phase rule that Gibbs's diagrams and surfaces

[68] Nernst, "Lehrb. d. theoret. Chemie," 2. Aufl., 564. Wind, *Ztschr. f. phys. Chem.*, 1899, XXXI., 390. Kuenen, *Proc. Roy. Soc. Edinb.*, 1899–1901, XXIII., 317; *J. Phys. Chem.*, 1899, III., 69. Le Chatellier, *Rev. gén. d. sc.*, 1899, 759. Saurel, *J. Phys. Chem.*, 1901, V., 31, 401. Trevor, *ibid.*, 1902, VI., 185. Wegscheider, *Ztschr. f. phys. Chem.*, 1903, XLIII., 93, 113. Raveau, *Compt. rend. Acad. d. sc.*, 1904, CXXXVIII., 621. Mueller, *ibid.*, 1908, CXLVI., 866.

[69] Roozeboom, "Die heterogenen Gleichgewichte," 1901, I., 7.

[70] *Ztschr. f. Elektrochem.*, 1907, 94.

have proved of greatest value. The triangular diagram which he originally proposed for this purpose[71] has been so improved by Roozeboom[72] that the study of the chemical changes of a heterogeneous system and the prediction of its possible degrees of freedom become for the skilled worker a simple and easy matter.

Scientific Applications of the Phase Rule.—The doctrine of phases gives the chemist a new way of looking at things, serving at once as a basis of classification and a guide in qualitative research, and in contradistinction to the older gravimetric chemistry which dealt with some one continuous state of an isolated substance, it inaugurates the chemistry of substances in contiguity. Here the phase rule bears the same relation to physical chemistry that the periodic law of Lothar Meyer and Mendelejeff does to inorganic chemistry. Although only qualitative in its application it gives the chemist a new *fundamentum divisionis* by components and phases, necessitating a revision of substances, of which many formerly recognized as compounds are now no longer listed as such, while many new compounds have been introduced.[73] In analytical chemistry the phase rule has found its widest application in classifying our knowledge of the dissociation of solid substances such as alloys, solid solutions, cryohydrates, tartrates, basic double and racemic salts, or in the solution of such special problems as the changing solubilities of metallic hydrates or the distributions of a dissolved substance between two solvents which do not mix. For example, Roozeboom discovered by the phase rule that four different hydrates can be formed with ferric chloride, of which only two were known before his investigation,[74] while van der Heide's studies of the double sulphate of potassium and magnesium (Schönite) revealed the possibility of at least fifteen heterogeneous modifications of phase.[75] No less than thirty different ferric sulphates are now on record,[76] and Bancroft has said that a general system of qualitative research is not possible until we have studied the properties of such multi-component systems. Tammann's researches on the equilibria subsisting between solids and their melted states indicate that nearly all such substances have more than one solid modification of phase,[77] while van't Hoff

[71] Gibbs, *Tr. Connect. Acad.*, III., 176.

[72] Roozeboom, *Ztschr. f. phys. Chem.*, 1894, XV., 143; *Arch. néerl.*, 1895–6, XXIX., 71. Bancroft, *J. Phys. Chem.*, 1896–7, I., 403. In 1891, Sir G. Stokes suggested the graphic representation of physical states of ternary alloys by means of an equilateral triangle which he derived independently from Maxwell's color diagram. (*Proc. Roy. Soc. Lond.*, 1891, XLIX., 174.)

[73] See Professor Bancroft's *Journal of Physical Chemistry* (*passim*), from which most of the results in this section are taken.

[74] Roozeboom, *Ztschr. f. phys. Chem.*, 1892, X., 477.

[75] Van der Heide, *ibid.*, 1893, XII., 416.

[76] Cameron, *J. Phys. Chem.*, 1907, XI., 641.

[77] Tammann, "Kristallisieren und Schmelzen," Leipzig, 1903.

has completely revolutionized our knowledge of the double salts and of geological formations. One of the most beautiful applications of the phase rule is found in van't Hoff's investigations of the oceanic salt deposits at Stassfurt,[78] in which from a laboratory study of the equilibrium obtaining between the sulphates and chlorides of sodium, calcium, magnesium and potassium the great chemist was able to reconstruct the past history of the formation of the earth's crust from the primeval ocean, giving even the limits of time, the pressure and the probable temperature at which the water evaporated. The importance of such methods in mineralogy and geology is self-evident and clearly as extensive as the subjects themselves. In metallurgy the work of Roozeboom, Le Chatellier, Sorby, Stead and others on steels, bronzes, tins, alloys and ingots of metal generally have, with the aid of the microscope, given us most valuable knowledge of the continuous chemical changes and "diseases of metals" going on in these substances, which, without the guidance of the phase rule, were formerly investigated in an aimless and haphazard way, at enormous expense and waste of time. Investigations of the very complicated equilibria in such "solid solutions"[79] as carbon-steels, nickel-steels, cobalt-steels, etc., have explained the causes of brittleness and crystalline structure in steel-rails through extended use, and how such rails can be renewed by prolonged heating at high temperatures. "The variations of the engineering properties, such as tensile strength, torsional resistance, ductility, etc., with varying concentration and varying heat treatment, is a subject which can only be worked out satisfactorily with the phase rule as a guide," says Bancroft, and he adds, "we do not yet know one half the properties of our structural metals." The establishment of the true constitution of Portland cement is another telling application of the phase rule and it is thought that it will give us "clearer ideas as to the strength of cements and the elasticity of clays." Lord Kelvin expressed the hope that some day the architect might be in effect a sanitary engineer,[80] and Bancroft predicts that "the time will come in our engineering schools when the subject known as 'materials of engineering' will have to be taught by the chemist rather than by the engineer."[81]

In agricultural chemistry the phase rule serves as a guide in the

[78] Van't Hoff, "Lectures on Physical Chemistry," Chicago, 1907.

[79] Solid solutions are solids dissolved in solids, and were first described by van't Hoff (*Ztschr. f. phys. Chem.*, 1890, V., 322), who found that when certain solutions are frozen, the separated solid is not the pure solvent, but a mixture of the selvent and the solute, *i. e.*, a solid solution, of which we have examples in the alums, glasses, colored and hyaline minerals, alloys and the "ice flowers" of the Antarctic regions.

[80] Kelvin, "Popular Lectures," 1894, II., 210.

[81] Bancroft, *J. Phys. Chem.*, 1905, IX., 209.

investigation of soils. "The soil is the stomach of the plant," being in effect a complex system in three phases, of which the liquid phase furnishes the nutrient solution to the plant. The bacteria, molds and enzymes in the soil make its relation to the plant a complicated and difficult problem,[82] but the application of physical chemistry to its solution of Cameron, Bell, Briggs and other chemists in the United States Department of Agriculture is clearly in the right direction. Recently Bancroft has shown how the phase rule may be applied to photochemistry when the radiant energy of absorbable light such as ultraviolet is converted into chemical energy. The light acts as another variable requiring $n + 3$ phases in an invariant system while in general we may have as many additional degrees of freedom as there are kinds of light.[83] The application of the phase rule to organic chemistry is difficult owing to "passive resistance to change." Most of the reactions in organic chemistry are reversible, *i. e.*, proceed to equilibrium, and if sufficient time be allowed will reverse backwards like a Carnot cycle, to some approximation of their initial state. Many reactions with organic substances, however, seem to stop short of equilibrium, and the chemist, in working with colloids, ferments, gums, etc., is balked by certain passive forces, which do not, like friction or viscosity, merely retard chemical change, but actually prevent it. Even such explanations as the hypothesis of reversibility in infinite time or Duhem's theory of false equilibria and pseudoreversible reactions, do not entirely account for these mysterious phenomena, and it is probably through new methods of laboratory procedure that organic chemistry will ultimately pass into the hands of the physical chemists.

In physiological chemistry the doctrine of phases opens out a new perspective, a new qualitative way of envisaging problems which, approached quantitatively, are a severe task even for an Emil Fischer. Recently the Dutch physiologist Zwaardemaker has proposed the application of the phase rule and the second law to general physiology.[84] "The task of an energetic histology," he says, "would be to give the number of phases and their relations, while an energetic physiology would determine the equilibria and reversible processes by direct experimentation."[85] Zwaardemaker proposes to regard the human body at rest as a complicated system of coexistent phases in equilibrium, the metabolic, reproductive and other processes of which are irreversible. The animal cell he holds to be a system of heterogeneous phases, the equilibrium of which can be disturbed by experimental removal of the nucleus. The red blood corpuscles are probably divariant, four component systems of four phases, while the endothelial cells of the ven-

[82] Cameron, *ibid.*, 1904, VIII., 642.

[83] Bancroft, *ibid.*, 1906, X., 721.

[84] Zwaardemaker, "Ergebnisse d. Physiol.," Wiesbaden, 1906, V., 108.

[85] *Loc. cit.*, 154.

tricle of the heart are examples of a monovariant system. The "pressure phosphenes" of the retina, luminous sensations produced by pressure on the eyeball, and consequently "eye strain," may be due, Zwaardemaker thinks, to displacements of equilibrium through disturbance of the thermodynamic potential. These speculations are, of course, tentative, but there are indications that physiological problems may be attacked in a way that has some show of success in that it is qualitative.

The Law of Critical State.—When we have two contiguous phases of a substance, as a liquefying gas or a vaporizing liquid, there is a point where the two become continuous. This is called the critical state at which the distinction between coexistent phases vanishes. Gibbs's law asserts that a critical phase of independently variable components is capable of $n - 1$ independent variations. This theorem is the basis of the brilliant work of van der Waals, Duhem, van Laar and Kamerlingh Onnes upon continuous gaseous and liquid states.

Osmosis and the Theory of Solutions.—Gibbs's work is remarkable throughout for his avowed or explicit intention to have "nothing to do with any theory of molecular constitution" as leading to strained and unnatural hypotheses, and the wisdom of his decision is seen in his earlier treatment of the equilibrium of osmotic forces. He bases his theory of osmosis upon the idea of a semi-permeable diaphragm or membrane, which he introduced into physics as a purely theoretical concept, leaving the actual facts about it, he says, "to be determined by experiment." This ideal membrane, which he supposes permeable to one component and impermeable to others, is the key to the theory of solutions, for, to the mathematician, it admits of the condition of reversibility which he finds in algebraic or chemical equations; to the physicist, a solvent in the act of breaking up or wedging its way through a dissolving substance is the dynamic analogue of a liquid forcing its way into a denser liquid through the membrane, while to the chemist, the assumption that the membrane is selective for certain substances only implies some special chemical affinity between these substances and the membrane itself. If two fluids of different composition or concentration, say water and alcohol, are separated by a semi-permeable membrane, the osmotic flow of the water into the alcohol is due to definite forces. These, in Gibbs's argument, are, not a difference in pressure, but a difference in temperature which disturbs thermal equilibrium or a difference in the chemical potentials *of components which can pass the diaphragm,* the condition for equilibrium being equalized temperature and equality of chemical potentials. "Even when the diaphragm is permeable to all the components without restriction," he says, "equality of pressure in the two fluids is not always necessary for equilibrium."[86] While Gibbs did not attempt a definite theory of solu-

[86] See his abstract in *Am. J. Sc.*, 1878, 3. s., XVI.

tions, it is clear that he regarded osmosis as a chemical or thermodynamic phenomenon. Let us see how his mathematical theory agrees with the facts of recent investigations. The mathematician Cayley thought double-entry bookkeeping an example of a perfect science, because its theory and practise are in complete agreement, so that the detection of sources of error becomes simply a matter of expert skill. For similar reasons one of the principal aims of modern physical chemistry has been to arrive at an adequate theory of solutions as a guide in chemical and biological research. Such a theory has been proposed by van't Hoff, who, starting from Pfeffer's measurements of osmotic pressure, bases his argument upon the widely known equation which asserts that osmotic pressure in very dilute solutions obeys the laws of Boyle, Gay Lussac and Avogadro with the same physical constants that obtain in mixtures of dilute or ideal gases.[87] Pushing this analogy with gases farther, van't Hoff implicitly denied that there is any specific attraction between the solvent and solute (dissolved substance) or that the alleged semi-permeable membrane plays any active part in osmosis, holding that "osmotic pressure," like the pressure exerted by rarefied gases, is a real initial pressure caused by a bombardment of the membrane by the dissolved molecules. Now van't Hoff's equation, which Gibbs anticipated for dilute solutions of gases in liquids, and of which van't Hoff, Lord Rayleigh[88] and Gibbs[89] have each given rigorous thermodynamic proofs, was found to be true to the laboratory measurements for extremely diluted solutions of sugar and other substances, but (as Lord Kelvin said ten years ago) "wildly far from the truth" for solutions of acids, bases and salts.[90] Arrhenius, in his theory of electrolytic dissociation,[91] has explained these discrepancies as "harmonies not understood," due to free dissociation of ions in water and to increase of molecular conductivity with dilution; but Lord Kelvin's objection has still some force to this day. Two schools of chemists have thus arisen, one of which seeks to approximate the laboratory facts about solutions to van't Hoff's dynamic analogy with the gas laws, the other holding that osmosis is bound up with an ascertained selective action of the semi-permeable membrane, osmosis and solution being both due to "chemical affinity." Most prominent among those who have opposed the view that real solutions behave like ideal gases, are Louis Kahlenberg and J. J. van Laar. The special service of Kahlenberg has been to discredit the molecular or dynamic analogy between gases and liquids and to emphasize the point made by Fitzgerald in

[87] Van't Hoff, *Ztschr. f. phys. Chem.*, 1887, I., 481.
[88] *Nature*, London, 1896–7, LV., 253.
[89] *Ibid.*, 461.
[90] *Ibid.*, 273.
[91] *Ztschr. f. phys. Chem.*, 1887, I., 631.

1896, that "chemical forces are of a far more complex nature than electrolysis."[92] Accepting the contention of the van't Hoff school that the gas equation and the Arrhenius theory are only true for infinite dilution, Kahlenberg has turned a clever flank movement upon them by insisting that if liquids act like gases we should expect a solution of increased concentration to behave at least qualitatively as gases do on increase of pressure. As a matter of fact, although practically all gases act alike, different solutions do not, as a rule, and solutions of solids in liquids, or liquids in liquids, do not behave like solutions of gases in liquids or gases in gases. Furthermore, the Arrhenius theory does not agree with many facts about aqueous solutions, while it falls completely to the ground for solvents other than water. This does not mean that Kahlenberg opposes electrolysis or electrolytic dissociation as such, or that he would have us abandon hypotheses of such value before we have found better ones, but he insists that "the question why certain solutions, molten salts, etc., conduct electricity and others do not will probably not be answered until we can tell why a stick of silver conducts electricity and a stick of sulphur does not."[93] Morse and others have shown that the van't Hoff equation and the Arrhenius theory are true for very small dilutions, that is for solutions so mathematically ideal that they are practically independent of the nature of the solvent and the solute, but the experiences of Kahlenberg have shown that they are not always true for actual solutions of reasonable concentration. Moreover, the fact that the solute in tenth-normal solutions acts like a gas by no means explains all the phenomena of solution. Kahlenberg's experiments with semi-permeable membranes[94] show that such membranes, while passive for gases, are active or selective for different liquids, so that the initial movement and actual direction of the osmotic current are determined by the specific nature of the membrane itself and of the liquids bathing it. Semi-permeable membranes, therefore, exist as such, and although none are strictly ideal in Gibbs's sense, their true "semi-permeable" or selective character is indicated by Kahlenberg's discovery that in some cases true measurements of osmotic pressure can not be obtained unless the solution is stirred to increase chemical action. The semi-permeable membrane shows that osmotic

[92] "That other than purely electrical forces are operative in solution is indicated by Helmholtz's investigations of electrical diffusion through fine tubes." Fitzgerald, Helmholtz lecture, *Nature*, 1895–6, LIII., 297.

[93] Kahlenberg, *Phil. Mag.*, 1905, 6. s., IX., 229.

[94] Kahlenberg, *J. Phys. Chem.*, 1896, X., 141–209. Recently Tammann has advanced the view that in ideally diluted solutions the solute acts like a gas, while in concentrated solutions there is a chemical interaction between the solvent and the solute, and such solutions behave more like the solvent under higher pressure. (Tammann, "Ueber die Beziehungen zwischen den inneren Kräften und Eigenschaften der Lösungen," Leipzig, 1903.)

pressure is not an initial force, but a secondary hydrostatic pressure due "to the same affinity which produces adhesion, imbibition, absorption, adsorption, solution and chemical action." But all these forces are reducible in the simple reasoning of thermodynamics to the difference in temperature (Carnot's principle) and differences of chemical potentials which promote chemical change. As to molecular bombardment, "osmotic pressure," said Fitzgerald, in 1896, "is more nearly related to Laplace's internal pressure in a liquid which depends upon intramolecular forces, than to a gaseous pressure which is practically independent of the forces acting between the molecules."[95] Van Laar pictures a sugar solution of reasonable concentration as made up of crooked movements of molecules, slowly crowding upon one another, with no intervening spaces, totally different from the rapid billiard ball movements with wide repulsions that are supposed to obtain in diluted gases. Osmosis, in van Laar's theory depends not upon the molecules of the dissolved substance, but upon the solvent itself, which, having the higher chemical potential, moves toward the solute. To explain the phenomena of osmosis by appealing to an initial osmotic pressure, says van Laar,[96] is like saying that an angry man's loud talk and unseemly gestures are due to his red face.[97] Anger is the real cause of both. So the movement in osmosis, which produces a difference in hydrostatic pressure, depends initially upon differences of chemical and thermodynamic potentials. Beyond this we know absolutely nothing of the interaction between the solvent and the solute. Again Bancroft has shown that the pressure for finite solutions in osmosis varies with the heat of dilution, which again varies with the specific nature of the solvent and the solute.[98] All this brings us back to Gibbs's fundamental position that osmotic pressure "is a function of the temperature and the n potentials."[99] From this point of view, Graham's original doctrine, that osmosis is the conversion of chemical affinity into mechanical power,[100] is at once true to the mathematical theory and the laboratory facts. If now we agree with Whetham that "osmotic phenomena are intrenched in the strongest part of the vast lines occupied by the science of thermodynamics," it is clearly due to the early pioneer work of Gibbs that this vantage ground was gained in the first instance, while the molecular theory of osmosis remains in the debatable land of controversy and a true theory of solutions is still far to seek.

(To be continued)

[95] Fitzgerald, *Nature*, London, 1895–6, LIII., 297.

[96] Van Laar, "Sechs Vorträge über das thermodynamische Potential," Braunschweig, 1906, 3.

[97] *Ibid.*, 34.

[98] Bancroft, *J. Phys. Chem.*, 1906, X., 319–29.

[99] Gibbs, *loc. cit.*, 139.

[100] Graham, *Phil. Tr.*, 1854, 227.

SUGGESTIONS FROM TWO CASES OF CEREBRAL SURGERY WITHOUT ANESTHETICS

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FOR the first time, so far as I am aware, there have been placed on record two cases of cerebral surgery, accompanied by somewhat extensive explorations of the brain-substance, without the use of anesthetics. The suggestions afforded, and the problems further opened, by these cases are so interesting from the psychological point of view that it seems to be desirable at least to call to them the attention of this association. Only one of these cases has as yet been reported in print;[1] for some of the facts connected with the other case I am indebted to correspondence with the operating surgeon, Dr. Harvey Cushing, of Johns Hopkins University.

Briefly described, the case of which we have the fullest report was as follows. The patient, R. C., was 32 years of age, unmarried, a farmer and teacher, a man quite up to the average of his class in intelligence, and of excellent moral habits. Previous to the beginning of his present trouble he had been in excellent health. When nine years of age he received a slight blow on the head; later, he received a blow from a baseball bat which fractured his nose. No other causes of possible cerebral injury were discoverable. About the year 1895 he began "to suffer from curious nervous attacks, which came on without cause." These consisted of strange sensations in the head, and twitchings of the left calf. But there was no loss of consciousness and the seizures lasted only a few minutes. With these symptoms there subsequently became associated tingling sensations, which sometimes spread up the left leg even to the thorax and the left arm, and more extensive twitching of the muscles, spreading itself in the same direction. These seizures were followed by numbness in the parts involved; but until July, 1900, there were no fits with complete loss of consciousness; and at the time of the first operation loss of consciousness had occurred only six times, although during the ten years previous there had been several hundred seizures.

The patient had, however, been subject to headaches from childhood, and these became more and more severe after the nervous at-

[1] "Removal of a Subcortical Cystic Tumor at a Second-stage Operation without Anesthesia" (reprinted from the *Journal of the American Medical Association*, March 14, 1908, Vol. I., pp. 847–856).

tacks already described. For three months early in the year 1903, the headaches were particularly intense, and this period of intense pain in the head ushered in a period of definite occular symptoms, consisting of momentary attacks of blindness, followed by diplopia for two or three days. The headaches suddenly disappeared, but there was permanent loss of visual acuity, weakness of the left leg, and general nervousness.

At the time the patient entered the hospital, careful examination of the nervous condition gave the following results: The optic nerves seemed atrophied and there was some constriction of the visual fields. There was distinct hemiplegic limp on the left side, a slight weakness in the dorsal flexion of the left ankle, and possibly also in the flexion of the knee and hip. The reflexes of the left leg were also somewhat exaggerated. On the contrary, sensation seemed to be normal over the arm and hand. The deep reflexes in the arms and right leg were normal. The sensibility of the right leg and foot were without discoverable abnormality.

The conclusion of the diagnosis made at this time affirms: "It was evident that the patient was suffering from an organic lesion situated in the upper part of the Rolandic region, involving the cortex itself or lying just below it."

Four different operations were performed for relief of this patient, between the dates of November 22, 1906 and March 21, 1907. These were all unsuccessful and did not even reveal the cause of the malady, and this unfavorable result was chiefly due to the fact that the patient bore anesthetics—both chloroform and ether—so badly and the cyanosis was so profound and threatening as to compel the surgeons to abandon their attempts at further exploration of the brain, lest it might lead to a fatal result. Moreover these operations served to show that the exposed surface of the brain was entirely normal in appearance; and when this part of the cortex was faradized, there was no abnormality of motor response. "Clean-cut movements were elicited in the toes, lower leg and thigh." In the same way movements were also obtained in the thoracic muscles, in the lateral abdominal muscles and in the muscles of the shoulder; and from still lower centers were obtained flexion of the elbow and flexion of the wrist. Posterior to the central fissures no motor responses could be elicited.

Following the third operation, or on and after December 23, 1906, the seizures increased in severity. Aggravated by the weakness following an attack of bronchial pneumonia in January, 1907, the nervous symptoms increased to one or more daily, consisting of severe epileptiform fits which involved the entire body, and always with loss of consciousness.

The constant and urgent request of the patient for relief, at all risks, from his distressing condition, induced the doctors to attempt the fourth operation; and when this was unsuccessful even to the extent of revealing the abnormal conditions, to the fifth operation, which was without anesthetics and which is the one chiefly interesting from the psychological point of view.

This fifth operation was performed March 26, 1907. The bone flap was for the fifth time reflected; the dura was incised some distance outside the largest previous incision; an incision was made into the gyrus centralis posterior, which appeared somewhat flattened and yellowish in color; and about one centimeter below the surface the top of a thin-walled cyst came into view. By enlarging the incision until it measured 5 centimeters this cyst was removed; but below it a still larger cyst was disclosed, which was "in turn shelled out of its bed by pushing the brain away from it, and was in this way removed unruptured." The entire procedure lasted about three hours.

But what about the mental condition of the patient during this long-continued and extensive exploration and cutting and pulling of the brain and its integuments? We are informed that he was "interested," asking questions and conversing with the doctors most of the time. Although perfectly conscious, he "experienced no sensory impressions whatever, even when the dura was incised." The only discomfort, not to say pain, given to him by these extensive explorations of his brain, was when the edge of the incision of the dura was caught in a clamp and the membrane dragged upon. The patient himself called the attention of the surgeons to an otherwise unnoticed phenomenon which consisted of a slight twitching of the muscles of the left side and shoulder.

In his report Dr. Cushing expresses his regret that this rare opportunity was not seized in order to test the effects of stimulating the posterior and post-central convolutions upon the experience of conscious sensation. In a subsequent case of cerebral surgery without anesthetics, however, these convolutions were stimulated and distinct impressions of sensations were obtained which were localized by the subject in the extremities and not at all in the cortex itself.[2] No such sensory impressions were obtained by stimulating the pre-central area, or "motor strip," although the customary motor results were obtained. Further details of the second case were not at my disposal at the time of writing this paper.

The following remarks upon these surgical results as viewed from the psychological point of standing are intended as suggestions rather than as definitely established conclusions.

[2] Still more recently, as I have learned in conversation, in a third case of cerebral surgery without anesthetics, the same operator obtained similar results of conscious sensations by faradizing the same region of the cerebral surface.

And, first, it would seem that the cerebral hemispheres, including their integuments, are largely or completely devoid of the capacity of self-feeling. It has been known for some time that the substance of the brain is insensitive to pain; but it has hitherto been held that the dura is a highly sensitive tissue. This belief was strengthened by the knowledge that this membrane receives its innervation from the trigeminal nerve, and by the experience that in trephining the lower animals, when the dura is reached, struggling, and rise in blood-pressure are common. But here was a fully conscious subject, able intelligently to describe his sensations, who felt no pain while the membranes over that part of the brain which is allotted to sensory impressions were incised and manipulated. This experience, therefore, throws back upon us the problem: What is it that causes intracranial pain, especially in the form of those intense headaches which follow upon disturbances of the cerebral blood-supply, or in cases of cerebral lesion like that now under discussion? May we not find that the causes of the pains which we locate in the cerebral hemispheres invariably lie outside of those hemispheres? Certainly, it is not strange that the localization in such cases should be even more indefinite than in the case of an aching tooth or some form of abdominal distress. Indeed, cerebral pains and other forms of discomfort, with their accompanying mental disturbances, may be so severe as to result in insanity, and yet the location of the irritating causes, whether nearby or remote from the brain, remain undiscovered.

Second, there is both additional light and increased confusion contributed by these cases of cerebral surgery without anesthetics to the problem of the functions of the post-central and so-called sensory convolutions. In both these cases stimulation of the motor strip called out motor responses; stimulation of the post-central area failed to call out motor responses. More important still by far is the fact that, in the second case, stimulation of the post-central convolutions was followed by distinct sensory impressions—not mere signs of such impressions, but conscious sensations, testified to in language by their subject; and these sensory impressions were located in the extremities and not at all in the cortex itself. This is definite and fairly conclusive evidence to the functional value of the post-central convolutions. But now, on the other hand, we have the fact that, although the incision was made in the middle of the field supposed to be especially if not exclusively sensory, no subjective sensations whatever were called forth in this way; and the yet more startling fact—I quote the words of Dr. H. M. Thomas, clinical professor of neurology in Johns Hopkins University—that,

> With a tumor situated in large part in the post-central convolutions and involving a considerable portion of its superior part, there was practically no objective sensory loss. I think it may fairly be said that before the first

operation, even after numerous and thorough examinations, no definite objective sensory disturbance could be detected. The tests were particularly devised to estimate the power of localization and the power of recognition of objects felt.

All this accords with the evidence upon which our whole localization theory is based. This evidence tends to show: (1) that the different forms of mental functioning are not absolutely dependent upon definitely circumscribed and permanently fixed portions of the cerebral hemispheres; and (2) that by mental development a relative independence of the particular areas originally connected with the different forms of mental functioning may be attained. From the physiological point of view the cerebral substance appears as plastic and educable to a degree until recently unsuspected. And any dislocation or interruption of the proper connections becomes more dangerous than even a considerable loss of the brain-substance. From another point of view the same conclusion was reached in a paper entitled "A Suggestive Case of Nerve-Anastomosis," which I read before the Psychological Association at its meeting in 1904. I take this opportunity to call attention to the fact that Dr. Cushing by a purposeful division of the facial nerve and its anastomosis with the spino-facial, has more recently succeeded in restoring to the patient a considerable degree of normal emotional control of the expressive muscles of the face. I leave to expert physiologists to conjecture what new adjustments in their related forms of functioning this required from the cerebral hemispheres.

Third, these cases of cerebral surgery without anesthesia would seem further to confirm what has for some time been held to be true —namely, that slow abnormal developments, even when they finally involve much more serious destruction of the cerebral areas, and interruptions of the normal connections, are tolerated much more easily than sudden and rapid lesions or other abnormalities. Nor does it appear wholly out of place to say that while this education of the cerebral hemispheres to unwonted functions requires time, the emotions and will of the conscious agent are factors of the greatest importance in securing the results of this education.

Finally, there is one thought which I bring forward, not as a matter of argument, much less of proof; but, the rather, as a personal impression amounting almost to a conviction. In stating this impression I will take the liberty to employ the language of an "old-fashioned" but by no means altogether discredited psychology. Here is an intelligent human soul; he remains perfectly conscious, free from pain, and taking a lively interest in a surgical operation which explores, incises, pulls about, and otherwise manipulates, and finally drags two large abnormal growths out from, what is known to be the most important part, for the life of conscious sensation and voluntary motion, of his own brain. From the anatomical and physiological

points of view, this picture is sufficiently startling. But when I take the more purely psychological point of view, I am impressed with the conviction that we are here dealing with the reality of a soul, as a spiritual agent, which while it is confessedly dependent for its development upon the development and normal functioning of the nervous centers, is, nevertheless, capable of attaining in the exercise of its higher and more complex forms of self-consciousness, a relative independence of those nervous centers. And if we ask ourselves whether this independence *may* perchance become absolute, after the destructive forces of nature have completely disintegrated the cerebral substance, we can not, indeed, answer "Yes," with the certainty of positive science. But upon my mind the impression made by such experiences as these is favorable to the affirmative answer. And so far as positive science can answer the inquiry at all, or even throw much light upon it, I prefer to follow along the lines of the seen and tangible and universally verifiable, rather than take the leap involved in a premature interpretation of doubtful phenomena by hypotheses touching the wholly unseen and intangible. Here, at any rate, is this conscious soul, manifesting itself as a partially "disembodied spirit." Its voice I can hear and interpret as one of my own kind. This manifestation appeals to me at present, and in accordance with scientific methods, much more strongly than any alleged communications from wholly disembodied spirits. Perhaps, however, at sometime in the future of the physical and psychological sciences, the two voices may speak with one accord.

HYSTERIA AS AN ASSET

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AT about the time that Commodore Vanderbilt was establishing in America the methods which made railway travel easy, a book was published in London which left untouched all problems of construction and management, but nevertheless played an important part in the economics of transportation. This book treated of railway injuries and was written by England's foremost surgeon, John Eric Erichsen. It brought together for the first time, in concrete form, the nervous disturbances from which the victims of railway wrecks suffer so severely; and by chronicling the large sums of money awarded in such cases as were litigated, it showed how important an asset "railway spine" might be. It soon became a best seller. It was indispensable to physician and attorney alike; and transportation companies had to have it to protect themselves against the menace of the new disease. It almost became a court manual at this epoch, when the quickening of railway movement was beginning to crowd court calendars with damage claims. For nearly twenty years it stood unchallenged and without a rival. Its influence was felt the world over, for it carried with it a money importance such as seldom follows the writings of medical men.

All this was half a century ago. Since then, new knowledge and new ways of getting it have shown that Erichsen taught mostly error; and his monograph, once so opportune and never to be stripped of the glory of the pioneer, is nothing now but a historical document. It was a costly book for railway companies. The cases it described were serious and "railway spine" brought large verdicts. It was not until 1882 that its teachings were seriously questioned. Then Page, surgeon for the London and Northwestern Railway, took a hand. In vigorous language, he presented new facts as seen by the railway surgeon. He brought forward the after histories of over two hundred cases of railway injuries and showed, contrary to Erichsen's teachings, that a large proportion of them recovered. He wrote with candor, but being a corporation servant, could not escape the charge of bias.

But Charcot was not biased, and when, in his studies of hysteria, he began to demonstrate the mental origin of many physical symptoms, the subject received its true illumination. Thoughtful physicians could no longer fail to realize that railway injuries are not essentially different from any others; that the mutilations are such as surgeons see resulting from a variety of causes, and that the nervous symptoms which so often

follow accidents on railways are mental rather than physical and are the same as originate from any one of a great number of emotional experiences. And so "railway spine" passed away and in its place came physical injuries and several groups of psychic phenomena which a great German called the "traumatic neuroses"—"traumatic" because of the accident, "neuroses" because the nervous system, though out of order, has sustained no physical damage and is capable, sooner or later, of resuming its normal functions.

With the spread of industries and the ever increasing frequency of claims for damages for personal injuries, these cases have become everyday occurrences. Physicians the world over have had abundant opportunity to observe their mode of origin, their course, and (though this with greater difficulty) their final outcome. And there is almost universal agreement of opinion that fright at the time of the accident and anxiety after it are the true causes. The cuts and bruises which must be received if the injury is to be actionable (151 N. Y.) intensify the psychic factors. But they do not cause the nervous symptoms, though they may determine, to some extent, their trend.

That this agreement of opinion is not always manifest when these cases come to court may cause regret but not surprise. Witnesses are not always candid, nor experts always wise. And the individual case itself may present such baffling perplexities that it imposes not only on judge and jury, but on the most learned professors in the land.

In Erichsen's day, diagnosis was uncertain in all the disorders at present called the traumatic neuroses. Now, most of them, such as neurasthenia and the various trains of morbid thought which result from back-strain, can be recognized at their true value by any physician who is reasonably experienced and careful. Not so hysteria. This mocking psychosis, with its tragedy and humor, its counterfeits and its realities, its impositions and its appeals for pity, is ever on the watch to lead the unwary into error.

In September, 1899, in Norfolk, Va., the cart which a healthy farmer was driving was struck violently by a trolley car. The man was for a moment prostrate on the roadway, but whether he was thrown out or had jumped out was one of the questions which perplexed the jury. At any rate, he walked to the sidewalk and then swooned. He was carried to a neighboring house, where he had a series of convulsions. The bystanders, strong men, tried to restrain him, but he threw them off. He then fell to the floor in such a way that only heels and occiput touched it. And in this strange posture, with body arching toward the ceiling like a bow, his frame was shaken during several minutes by violent trepidations. He was finally carried to the hospital, apparently unconscious. No evidences of physical injury were found. But the next day he complained of pain down the whole right side and there were twitchings of the face and arm. A few weeks later he became

deaf and dumb and shortly after that lost the use of the right arm and the right leg.

In this condition he was brought to court, eight months after the accident, the most important witness in his suit against the street railway company. There never was a fairer trial. Opposed experts coincided in the view that the plaintiff had received no injury of important organs and that his dramatic symptoms were the physical expressions of idea. It was a tribute to the dignity of honest experts that the judge, in the face of the exhibit, listened calmly to this testimony and that the jury did not laugh out loud. For the poor man seemed sitting in the shadow of the tomb. Emaciated, his face agitated by constant twitchings, his whole right side inert and powerless, hearing nothing, uttering no sound, getting his questions on slips of paper and writing the answers with the left hand (an accomplishment acquired since his illness)—he looked the leaf about to drop, the very essence of decay. Optimist indeed who could believe in his rehabilitation.

The jury disagreed, mainly on the negligence, and the case was settled a few months later out of court. The man recovered, not all at once, but gradually. He now hears everything, and, if his wife is to be believed, talks too much; his muscles have regained their power and, when not busy on the farm, he ferries passengers across a little river in the county of Princess Anne. So the doctors, all of them, were right for once, for hysteria and nothing else can explain a case like this.

As a psychological proposition, this strange malady more than demonstrates the influences of mind on matter—it establishes the dependence of all voluntary expression on idea. It can disrupt mental and physical unity as completely as the most destructive injuries. Its dark shadows flitting in the subconsciousness corners of the mind may stimulate to increased function, or so far suppress function that the affected organ is left without its purpose. Hypersensitiveness, which soon is pain, to light, to sound, to smell and taste, to feeling, may all be products of hysteria when the disorder whips up function; when it paralyzes, the victim must get along as best he can until his sensorial servants come back to work. In the sphere of motion, twitchings, tremors, contractions and even convulsions, bear witness to excess of function; paralysis, to loss of it. These functional perversions, these idealistic symptoms, are cast in the same mold as those of structural disease. But they carry with them tell-tale differences of form and arrangement which permit their true nature to be recognized. Various and many are the hypotheses to explain the psychological enigma. For its last analysis it needs the genius of a Plato. For working purposes, perhaps the theory of Charcot is the most acceptable. He compared the genesis of traumatic hysteria—which alone concerns us here—with the mechanism of hypnosis. The jar, the blow, the fright, like the passes or the artificial aids of the hypnotist, create disorder in the mind,

dazing it and reducing it to extreme impressionability. Then follow the suggestions. Verbal from the hypnotist, to the hypnotized victim of the casualty they come from the circumstances of the accident, or what follows it, or from the victim's mind itself, as it reflects on injuries he has seen or heard of resulting from similar disasters. Thus is determined the symptomatic type. Little by little the symptoms spread and deepen—they rarely reach their full development at once—until at last, the patient, sound in wind and limb, may become as inert a mass as ever wheel-chair carried.

As important as the accident itself, or even more so, are the circumstances which follow it. Injudicious sympathy from friends, fears felt by physicians not wise enough to keep them to themselves, the solicitous exaggeration by attorneys and the patient's perception of the financial possibilities of his wrongs, all give new tentacles to the morbid ideas, which burrow deeper among the roots of rational conduct. Left to a physician versed in psychic medicine and rich of conscience, with damage claim thrown out the window, there are few cases of traumatic hysteria, taken at the outset, which a month of vigorous treatment would not cure. But, with the demands of legal procedure ever imminent, such a course is never possible. In Germany and other countries which maintain parental protection of the injured, conditions are even more unfavorable. In these countries, the injured workman is placed on an allowance of money, graded in accordance with his earning, which continues to be paid as long as he is incapacitated. This robs the patient of his spur to effort and tends to prolong the mental instability. As a result, in these countries, or at least in Germany, traumatic hysteria is more protracted and rebellious than it is with us. With us, sooner or later, the case is finished. It may be years before the final card is played; but some day the game is over and the hands are on the table. And then, for the first time since the accident, the injured person has a chance to regain his health. Before there was no chance. For, with the persistence of symptom-inducing suggestions, inseparable from litigation, it is practically unheard of, if not impossible, for a plaintiff to improve in any essential particular before the release is signed or the court-room doors have closed upon him for the last time. This helps to make hysteria the most difficult disease of any found at law of satisfactory settlement out of court.

At the outset, the surgeon for the company, thinking the case is one of temporary shock, reports favorably and the claim agent makes offers of small sums. These are rejected; the plaintiff's physician has seen such symptoms aggravate with time. The attorney feels a conscientious duty toward his client and must know the way things are going before settlement is thought of. While they all thus solicitously wait, the gloomiest fears are realized. Paralysis sets in. By this time the dangerous character of the case dawns on the defendant. Head sur-

geons and neurologists are sent. These report the facts which usually are conspicuous enough. The patient gets still worse. All chances of settlement on any reasonable basis are now gone and the case finds its way to court. Once in the court-room, the patient is at the acme of all the symptoms. Paralysis, insensibility to pain, convulsions, loss of special senses, all make profound impressions on judge and jury. The medical opinions are too often flatly contradictory; and the jurors, thus deprived of the advantage of special knowledge, judge for themselves from what they see.

The verdicts are always large. None too large, perhaps, as actual amounts, in view of the suffering and delays the plaintiffs have gone through. But excessive when compared with the amounts paid for other injuries, more modest in their symptoms, but with far less hopeful outcome. A young girl with hysteria can generally secure a higher compensation in the courts than a working man with some lifelong disability. The amounts thus unjustly graded may indicate that juries can not grasp the dramatic power of idea; or else that they believe that symptoms conjured up from subconscious depths are even more persistent than those of tangible causation.

In strong contrast to the verdicts is the fact that hysteria from injury, in America at least, is cured in nearly every case. Such is my personal conviction,[1] based upon information obtained about the plaintiffs after the suit is closed. Into a detailed examination it is rarely possible to go. For after the trial these individuals, with surprising frequency, fold their tents and silently steal away. Those that remain within a reasonable radius rebel at the idea of reexamination. They seem to resent their recovery. A young man who was injured in one of the terrible wrecks occurring near New York a few years ago, lay in bed for two years with hysterical paralysis, awaiting the trial of his case. There were two trials. At each of them he heard, from his stretcher, his experts say his injuries were permanent. In spite of that he was up and walking freely and was commuting to his work, as he used to do, within eighteen months of the last trial. But a request, prompted by the writer, for permission to reexamine him, brought a response to the effect that "no information would be vouchsafed which could in any way be used to prevent others who had suffered as he had from being less generously compensated."

From such information as is obtainable, it would seem that full functional recovery is the rule. The women who were cripples often marry, the men return to work. But their assumptions or resumptions of activity are often slow. The patients may be well again in a few months. But the miraculous and instantaneous recoveries, such as we

[1] In "Diseases of the Nervous System Resulting from Accident and Injury," Appleton, 1906, the writer presented the after histories of a number of cases of litigated hysteria. Since then he has added many to the series.

hear of in the faith cures, or such as corporation partisans maintain follow quick on payment, do not come within the range of medical experience. It is always several months, sometimes a year or two or maybe even longer, before disabling symptoms disappear.

The farmer whose case has already been described suffered pain and disability for a year after his suit was finished and it was four years before he recovered speech and hearing.

Litigation permits no let-ups in the disease creating suggestions; and the longer the litigation period, the longer, other things being equal, the time required for cure. In the case of a young man injured in Washington, D. C., there were eight years between the accident and final verdict. During this considerable fraction of his life, the plaintiff was glued to his chair, the victim of paralysis from idea.[2] I am still confident of his recovery, though even now, eighteen months after the finish of the legal contest, he has not begun to walk.

The mechanism of recovery in these litigated cases is different than in the ones reported from the shrines of healing. In these latter, the priests make new suggestions, getting at the soul through anticipation, faith and religious fervor. In traumatic hysteria, the cures take place, not so much from fresh suggestions as from removal of those which worked the injury. New springs of action are not tapped; but the stones which blocked the old ones are one by one removed. Once the case is settled, the attorney's sympathy becomes homeopathic in its dosage; the physician abandons the contingent fee; family and friends, worn out by watching and satisfied at last that the patient will not die, resume their wonted occupations. The invalid is left, more and more alone. Under the fillip of neglect, the fixed ideas show signs of weakening. The patient reflects less and less upon his injury and begins to see, in the distance, perhaps, but every day more clearly, the smiling visage of Hygeia. His interest now is to regain his health and enjoy his money, as before it was to stay ill enough to get it. Little by little, he regains his balance and begins to hobble about the room. New trials and achievements add to his confidence, though he has occasional relapses. He gets out on the street and finds himself more capable than they ever let him think he would be. Then under the stress of some emotion, or forced by some sudden danger, the part paralyzed springs into pristine being; and soon after he resumes his work.

It has long been held that such cases are the products of voluntary creation and that the hysteric is an actor and a fraud. Such a view is surely wrong. No actor can ever equal the mimetic powers of this wonderful psychosis; and even if the hysteric is a fraud, who, at times, is not? The disease reflects, to some extent, the normal nature of its victims; but it reflects still more the environment in which it is born and lives and dies.

[2] Physicians on both sides agreed in this diagnosis.

Postscript

After this article was in type and the proof had been returned to the editor there was received from the plaintiff's attorney in this action the following letter, written by the plaintiff's wife:

Washington, D. C., April 26th, 1909.

My dear Mr. S:—

I fear that I am too happy to express myself intelligently, but you can understand the cause when I say Mr. P. has walked and it came about from a fright produced by the falling of plaster from the ceiling at three o'clock in the morning. Of course we were all sound asleep and when the crash came, I thought some one had bursted in the door and I went into hysterical convulsions and Mr. P. found himself several feet from the bed. He is very weak, but the Doctor says that he thinks he will gradually regain his strength as the sensibility has returned to his limbs. Oh, we all are so supremely happy and I feel sure that the Lord in his own good time will restore my boy to health.

Very respectfully,

Mrs. V—— P——.

NOTES ON CERTAIN PHILOSOPHIES OF THE DAY

By ALEXANDER F. CHAMBERLAIN, Ph.D.
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I. *The Rule of the Dead.*—M. Le Bon, himself now in the other world, would have it that we are suffering inutterably from a sort of universal *mort-main.* There is but one real case of majority rule on earth, that of "those who have gone before." Our masters and rulers are neither the select few among the living, nor the many-headed people, but the great hulking mass of the dead.

With *de mortuis nil nisi bonum* goes *e vivis nihil boni.* We praise the dead with our living tongues and let their inanimate hands act for us. Our thoughts, no less than our bodies, are heirlooms from the departed. Like the savage, we hear the dead whispering by the rivers of life and speak their words after them. We bear the burden of their sins; we reap the harvest of their mistakes and their calamities. Paul, the apostle, is not the only one who had the right to say "I die daily," for all men and women are in uninterrupted intercourse with the dead. Even children, just beginning to live, are schooled with dead languages. The old, in their second childhood, are counted already dead. Youth, so full of life, is taught the art of war, adding, by national command, to the number of the dead. Only when dead are the races that were here before us, like the Indian, "good."

Yet many great ones of mankind have longed for emancipation from the rule of the dead. Some adventurous psychologists hold out the hope that some day we shall control the past instead of being absolutely at its beck and call as we now are. The racial and the individual past shall both be ours and memory-guided progress will speed us on to the destined goal. Then, indeed, shall "old men dream dreams" and "young men see visions," and all who see in sleep, like Mahomet, shall see truly. Fear of the unconscious and dread of the past shall be lost in the conscious control of the experience of other days, of times gone by. Then shall they be, as we have fondly imagined them hitherto, the "good old days of yore." No longer shall we be the living tombs of the dead past that will not bury itself; no more phosphorescent merely with the immemorially defunct. We shall then have life, and life more abundantly.

II. *Mutability.*—Everything changes. As the old Greek philosopher said, flux is the very nature of things. Flora, fauna, races of men, civilizations, institutions, customs and habits, beliefs, ideas and

ideals, are in eternal metamorphosis. Schrader tells us this to-day as did Heraclitus long ago. The twentieth-century idea that its culture and its creations will endure may be false, as have been the ideas of Egyptians, Greeks and Romans. The conception of stability is an illusion. All passes and repasses.

Egypt for millenniums has been only a gift of the Nile renewed by its floods. The heroes of Homer are brigands to-day. The Roman Cæsar has become a Pope. Spain died when the Indies were born. The cliff-dwellings of Arizona and New Mexico speak of things past and gone. The Negritos, the Bushmen, the Ainu, the Lapps, the Eskimo are being driven to the wall. The fate of the American Indian is partly sealed. The Aztec is a peon; the Peruvian a cargador. The Beothuk and the Tasmanian are already gone. Britain is saved from being an insular Labrador by the Gulf Stream. Bordeaux survives only through its vineyards.

With the ebb and flow of industry and manufactures, villages, towns and cities spring up like mushrooms. Others have disappeared like the melting snow-flakes. The forest vanishes and the sea is encroached upon. Holland reclaims a lost country, America reanimates a desert. Rivers and lakes are dried up and mountains are hewn down.

But, after all, there is an illusion about this flux itself. To remind us of its relativity, the Fellah, direct descendant of the most ancient Egyptian, keeps watch beneath the pyramids. Before him have passed, as the ages came and went, Libyan and man of Punt, Sardinian and Hebrew, Persian and Babylonian, Greek and Roman, Arab and Turk, Frenchman, Englishman and American. And amid all their notable mutations he has remained practically the same. He still waits for the stirring of the waters.

III. *Imitation.*—Wise men before Solomon said "there is nothing new under the sun." And in all they have thought, said, done or dreamed, the ignorant in all times and among all peoples have corroborated the sages. The great majority of the wise, too, have labored zealously at the same task. To-day, Tarde tells us, imitation is everything.

Art is imitation of nature and nature imitation of God. God imitates himself. Civilization is mimicry. Genial repetition is the sum and substance of great knowledge and deep wisdom. Ignorance is gross imitation. Life and death are both imitative. By imitation childhood learns, youth hopes, manhood forgets, old age despairs. Heredity itself is imitation. Both the individual and the race have acted, "as if its whole vocation were endless imitation."

How hard it is for man to do otherwise than his fellows are doing or have done! To repeat is so much easier than to invent. To borrow than to create. To follow than to lead. To stand with the many

than to fall alone. Fortunately for mankind, evolution has set limits to the tide of imitation:

> There's a divinity that shapes our ends,
> Rough-hew them how we will.

IV. *Misoneism.*—If we believe Lombroso, *misoneism* or *neophobia,* "the hatred of the new," is one of the most deeply ingrained characteristics of man. Progress occurs only when there is a break in the neophobic series. The leaders of mankind are not the many who imitate, but the few who do new things, or think them. And many of these put new wine into old bottles—the makers of new vessels are rarer still. And woe unto those who, with new wine, break old bottles! The blood of such has been the seed of civilization, of the church, of science. Genius, prophet, saint, hero, sage are slain, and the world moves on a little, forgetting even to raise a monument to its great dead. Death baptizes new life: The fall of the few wise inspires a little the ignorant multitude. A martyr means more than a school or a church. On the dead hero springs up the living faith. The doctrine of "the good old days of yore" comes easily to man, who is naturally uncomfortable in the presence of the new. Yet the monotony galls. To take the kingdom of heaven by violence affords relief.

Reforms come from the acts of the few who destroy the old, or through the deeds of the many who slay the innovator. Death or ignominy for centuries has awaited him whose message is: "Behold! I make all things new!"

But not so forever! Slowly, but surely, men are learning wiser and better ways of hating and destroying the new, of preserving and continuing the old. The cessation of blind leadership of the blind means the orderly development of human society. Revolution is giving way to evolution. The old turns naturally and peacefully into the new. War will soon be as unhuman as murder.

An age is near in which we shall no longer imitate the errors of revolutionary epochs. We shall grow into the future by growing out of the past.

In that happy time we shall wonder that their bards could have sung the Celts into vain and pernicious wars; that her philosophers could have desolated Greece by making constitutions for her cities; that soldiers could have brought Rome to vice, luxury and decay; that priests could have led Judæa to reject Jesus for Barabbas; that gold could have brought Spain, once monarch of all the world, to nocuous desuetude. We shall know evolution and act in its spirit.

The philosopher will be content to see the passing of his own physical and mental minority before attempting to lord it over the bodies and souls of his fellows. The statesman will not venture to propound constitutions for states before he has learned to know the laws

of his own life. The soldier will not longer yearn to reenact on a grand scale among the nations the war of members and of parts which his own body and mind sustain in youth, but will seek to overcome it in the body politic as in his own organism. Thus will be verified the saying of Scripture: "He that ruleth himself is greater than he that taketh a city." The priest will as gladly serve, as once he ruled, the state. He will rejoice more in being a servant of God than a ruler over men.

V. *Struggle.*—Man's struggle with the elements has been even more successful than that with his fellows. The hours of final triumph have often been delayed by his own carelessness and dishonesty alone. Beginning with the arrow he won the all-encircling air, with the dug-out, the inhospitable sea, with fire, the inclement sky, with the digging-stick the unyielding earth to his service, or, at least, to his unhurt.

Since his first conquest—as Gallouédec suggests—of the hill-side and of the little mountains, he has become master of the plains, and now morasses and bogs, deserts and huge mountains are fast yielding to his sway. He lords it over unfathomable chasms, dizzy heights and wind-swept ocean. He makes the desert blossom as the rose, and from the very bones of earth coins and fashions things whose beauty is everlasting. He has harnessed the lightning, housed the sunbeam, and both have become the servants of art and of science. Things terrible to his eye and his ear, nay, that shook him to the uttermost depths of his soul, when he first trod the earth, are his familiars now. He has made nature his servant instead of remaining her slave. Gallouédec hardly exaggerates when he says that from the first man to the Frenchman or the Englishman of to-day is not a whit less than the distance separating the formless block of marble from the statue produced out of it by the genius of the artist. And the future bids fair to outglorify the past. The conquered earth, once the mere hiding-place of the savage, or his prison, is becoming more and more his home. Nature, who once held him in bondage, after being his servant, turns to colleague and friend. With the passing of war and the lust of human slaughter man is beginning to feel at home in the world and in the universe. And now the empire of the sky is beginning to be his. The future years will see the results of the leisure which progress in man, who alone of all creatures possesses the power to utilize the past and to discern the future, has made possible. Man will live and labor, transform and create in the full sense of his partnership in all about him, his slaves and servants having become his friends and co-laborers in the evolution of the cosmos. He will outdo Ulysses. He will become a part of all that he has met, and all that he has met will have become a part of him. Struggle will be succeeded by togetherness.

FORMATIVE INFLUENCES

By Professor G. J. PEIRCE
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WHEN I was a boy in New England it was the fashion to decorate the windows of the drug-stores with masses of huge deep blue crystals of copper sulphate—blue-vitrol or blue-stone. These ornaments have vanished now, even from the country drug-stores. Their places are taken by electrical toys, patent medicines, even animals. But these lumps of translucent crystals always interested me. Their composition is simple; sulphate of copper and water are their sole constituents. The sulphate of copper is itself a dull gray powder, not a crystalline substance at all; but if water is with it, it becomes blue, colors its solutions blue, and crystallizes in very regular form. The color and the form of these crystals depend, therefore, upon both water and copper sulphate.

The boy who plays with blue-stone, dissolving it in water and then recovering it again by crystallization, thus doing for fun what the freshman in a chemical laboratory does because he is directed, learns that the crystals will be large or small, few or many, according to the speed with which they form; large and few if they form slowly, small and numerous if they form rapidly. This is equally true of sugar, common salt and other crystalline substances. We see, then, that circumstances as well as substance have to be taken into account. Although we can not have crystals of this particular kind unless we have the sulphate of copper, neither can we have them, even with an abundance of the salt, unless we have water also. The water must not be in excess, lest the copper salt remain in solution; nor deficient, lest it remain amorphous. It must be exactly proportioned in quantity if the salt is to arrange itself into bodies of definite form. The size and the number of these bodies depend upon temperature, dryness of air, any circumstance, in fact, which influences the rate at which water evaporates from the solution.

Although the number, size and even the formation of blue-stone crystals depend upon circumstances, and will vary according to circumstances, circumstances can not make blue-stone crystals exactly like the crystals of other things. The crystals of common salt have characters which identify them to the eye and mind of the crystallographer. These characters, we say, are inherent in the substance itself. This may be true actually as it certainly is true practically; but a scientific man might be found who would hazard the opinion that common salt, which crystallizes in square plates with hollowed surfaces under the conditions which we know, might crystallize in

another shape or remain amorphous on some other planet where the force of gravitation, the composition and pressure of the atmosphere, and other factors of its environment, would be different from those constituting our environment on this earth.

Students of the natural sciences reckon with circumstance as well as substance. Physicists and chemists know this, and work with a conscious realization of this fact. Of the biologists, none more keenly realize the significance of circumstance to the organism than physicians and surgeons. Sociologists dispute whether heredity or environment determines the qualities of the man. Many botanists and zoologists meantime are discussing fine-spun theories of heredity based on the infinitely more finely spun microscopic structure of plant and animal cells, devising a scientific vocabulary which breeds dictionaries while it veils our real ignorance of the facts concerned.

The thorough study of mankind, or of any other living or lifeless thing, involves a study of the substance of the thing and of its environment. Study of the simple substance of blue-stone and of common salt is comparatively easy; but the bodies of living things contain and probably consist of many substances, few of which are as simple as blue-stone and common salt. Definite chemical compounds, many of them complex and unknown, constitute the bodies of living things. These compounds possess their own properties, their own characteristics, inherent if you choose. Their behavior controls if it does not constitute the behavior of the living thing. But this behavior depends on circumstance, is controlled by environment. The living thing, human or vegetable, can not be known till its environment as well as its substance, and the influence of the one upon the other, are known.

The chaplain of this university, coming to my laboratory one day, was surprised by some machinery which he saw there and asked its purpose. I told him that I was proving that, if you took a slum-child early enough, you could make a decent man of him. My friend protested that I was omitting many links between the plants of my experiments and the less fortunate of the human race. While frankly admitting this, a scientific man may still believe that he can contribute to such proof by using guinea-pigs, or rats, or even plants, as the objects of his experiments. These experiments are designed to furnish information about the circumstances, the influences, the factors of the environment, which affect behavior.

We see the various factors composing our environment directing the movements of our fellows. A bright light or an unusual sound at once attracts notice, may even draw a crowd. The absence of light, generation after generation, has cost cave animals their organs of vision. Who can say that the perpetual noise of our cities will not induce changes in the nervous balance, if not in the organs, of men?

The force of gravity, which enables a man to stand erect, defeats the unbalanced efforts of the baby learning to walk; it directs the growth of root and shoot from the sprouting seed; it forces organs and organisms to carry a very large proportion of their own weight or perish. When plants and animals live in water, over seven hundred and fifty times as much of their weight is carried for them as if they were growing in air. When plants are supported on trellises, or grow on trees, their mechanical strength, the development of their supporting tissues, corresponds to the lessened load. The buoyancy of the water and the mechanical support of trellise or tree, opposing the pull of gravity, modify and reduce its formative influence.

If we compare the great brown kelps growing along the rocky parts of the Pacific Coast, attached by hold-fasts to the bottom, floating upward and along the surface of the ocean till they become the longest plants known, with land plants, we find only some trees and such vines as the rattan at all approaching them in length. But in structure and in mechanical strength, what a difference there is! Bring the seaweed ashore and try to stand it up; take the vine down from its support; neither will be able to sustain its own weight. The force of gravity opposed, in the one case by water, in the other by the forest trees on which the rattan grows, has not exerted its full influence on either. The tree stands, and its trunk is composed of mechanically strong tissues, in part at least because of the pull of gravity only feebly opposed by the air.

Experiment proves the formative influence of gravity. The English gardener who trains his peach trees on the southern face of a wall knows well that such trees are mechanically weaker, though more prolific, than other peach trees growing unsupported in the same enclosure. The delicate stalks of the blossoms of apple, peach or prune, thicken and strengthen as the fruit sets, grows and ripens, the increased pull of gravity stimulating the living stalk to meet the greater strain by greater strength.

When we take into account the fact that the force of gravity acts constantly, that though we ordinarily ignore it or take it unthinkingly for granted (as we do the quality of our milk), it is an unchanging force, the same night and day, from season to season, from cycle to cycle, we begin to realize that it must exercise a formative influence of the utmost importance on all living things, stimulating the growing plant and animal to develop an adequate skeleton and to attain a balance of parts which will tend to stability.

Water opposes the force of gravity by buoying up, and carrying so large a fraction of the weight of, the creatures living in ponds, streams and the sea. In addition, it has a positive influence of its own. We are used to the directive influence which causes the wild creatures of field and forest to make the runways between den or nest and water-

hole so charmingly described by Mrs. Austin. Every trout-fisherman has seen the roots of alder and willow growing from the bank into the stream. We are accustomed to having our house-sewers stopped up by the roots that *will* grow into them, though there is much more room outside. But the formative influence of water is not so obvious. Yet when we think of the creatures, plants and animals, of arid regions and of well-watered ones, we perceive certain differences. When we realize that water is formed, or is the surrounding medium, in almost every chemical reaction which takes place outside the living body, and in every chemical reaction within the living body, its importance is evident enough. The shape, size, structure and covering of every animal and plant are influenced by the ease with which water may be obtained and held. All land animals and plants lose water from their bodies by evaporation; submersed aquatics do not. Land animals and plants ordinarily get water from the earth, from depressions in its surface or from its soil, and only through those limited parts of their whole bodies which touch the water; but aquatics can take it in through their entire surface. If a land plant or animal takes in water only through its roots or its alimentary canal, there must be some system for distributing the water to all the parts of the body; but this is not necessary in aquatics. The differences in structure and form between land and water organisms is, then, partly due to their relations to water. The differences between the tadpole and the frog, between the submersed and floating leaves of the water-buttercup, between the swimming sperm of moss and fern and the wind- or insect-borne pollen of the higher plants, these differences are in their relations to water, in the degrees in which the formative influence of water has been unopposed by other factors.

Before turning to other formative influences, we should realize that the force of gravity acts constantly, night and day, uniformly, age after age, and it is impossible either to eliminate it in experiments or to conceive of its operation ever being or having been interrupted in nature. Water also is constant and uniform and unavoidable; for until water ceases to be a necessary component of the living protoplasm of the plant and animal body, until it becomes something else than hydrogen and oxygen in the proportion of two to one, we can not conceive of its being eliminated, by exclusion or substitution, in experiment, or of its absence in nature. If water is absent, life is absent. This is not true, however, of other influences, material or energetic, which affect form and substance, as well as the direction of growth or movement. These influences may be temporary.

Light is not a necessary condition of active life. It comes and goes, day and night. In the extreme northern mid-summer the sun never sets; the winter is dark and gloomy. In spite of the lack of light, however, life goes on in the winter darkness provided sufficient

warmth is attainable. Nor is light uniform, for though the total seasonal light-fall may be, like the total seasonal rainfall, a moderately uniform quantity, yet we know that the light which reaches our eyes and plays on field and forest varies almost from moment to moment, as a wisp of cloud, a trail of smoke, or a bird or butterfly, passes between us and the sun. Yet with all this variation in quantity from day to night, and even from moment to moment, there is no variation in quality. The composition of sunlight, as it reaches the earth's atmosphere, is the same age after age; its red, yellow, blue and other rays fall upon animal and plant in similar proportions. Until the source of light changes, until the composition of the sun becomes altered by the exhaustion of this or that substance, the quality of light must continue the same.

The leaves, stems and flowers of our household plants turn toward the window. Plants growing under a hedge turn out to one side, if they are able to bear the shade long enough to get out of it. In the early morning, or toward sunset, one can often see the leaves of weeds all turned eastward or westward, according to the source of light. These are familiar instances of the directive influence of light, an influence which changes with the direction and the intensity of the light and is dependent upon some, not all, of the rays of ordinary daylight.

The formative influence of light is no less real and definite, although not so generally recognized. It determines whether a plant shall be stocky or straggling, short or long. Greenhouse men speak of spindly plants unduly shaded as "drawn." The ordinary broad, brown bean —Windsor, or Horse, or Spanish—sown in quantity in the vegetable gardens of those parts of the west where the paths of the padres lay—correspond in height quite as much with the light they receive as with richness of soil. If sowed too closely, each plant over-shading its neighbor, they grow in the same length of time to nearly double the height of others solitary. Young pines in too close stands are tall, slender, sparingly branched. The low stature of some of the plants of mountain-tops is due not merely to crushing snow, brief growing time, and chilly nights, but also to the greater brightness of the light which falls on them than on the floor of the valleys below.

Thus the vegetative parts are affected quantitatively by the quantity of light which reaches them. Stem and leaves reach their ordinary dimensions only under ordinary illumination. There are structural differences between the sunned and shaded leaves of wild plants. The beech offers the best known case.

Eastern greenhouse men spend anxious days before Easter lest their lilies bloom too late. They can control the temperature, moisture, soil, in their houses, but beyond certain narrow limits they can not control the light. The same plants bloom at a decidedly lower temperature in California than in the Mississippi Valley and on the

North Atlantic slope. When the Weather Bureau can give as accurate measurements of the amounts of light reaching the soil in these different regions as of the temperatures, we shall see one reason for this difference. Even though flowers may be already formed, a certain though unknown amount of light is generally necessary to bring the flowers promptly to perfection. More than this, the number, size, color, fragrance and other qualities of the flowers, the number of eggs and sperm in them, even the formation of the flowers themselves, are dependent in very many plants upon an amount of light more than sufficient to maintain vigorous growth. This has been clearly shown by experiment on so many plants, simple and complex, as to lead one to think of light as a definite stimulus to reproduction. I can grow certain moss-like plants year after year in my laboratory and, according to their position, in a light or a dark place in the room, they will form reproductive organs or will remain sterile. I can do the same thing with submersed water-plants, and in garden and greenhouse the same fact is demonstrated year after year.

John Muir, in his "Mountains of California," gives the most glowing description of spring bloom which I know, where he tells of the San Joaquin Valley before it was settled. The newcomer to California to-day is struck with admiration of the great mats of color on hill-side and valley-floor. This prodigality of bloom far exceeds what one sees on either slope of the Alleghanies. Transplant the California "poppy" to any less sunny land and it degenerates; it blossoms less freely, its flowers are smaller, its petals are more sulphur or lemon than orange-yellow, its seeds are smaller and fewer. It seldom grows, still less blooms, under the shade of the live-oaks, though the open field may be golden with them. The more shade, the less bloom.

Testing this conclusion by experiment on plants very different in shape and size in their vegetative and reproductive stages, as is the case in *Sempervirens* and similar squat plants used for bedding or bordering, it has been found that the reproductive stage may be indefinitely postponed by growing the plant in feeble diffused light. Rather more light stimulates the plant to send up a stalk from its rosette of leaves, but this stalk is leafy. Still more light will induce the formation of flowers; but only when fully illuminated will the plant form perfect flowers and set good seed.

Cultivated violets are from eastern and European stock. In the middle west, in New England and in northern Europe, violets of many species form, in addition to the conspicuous blue flowers, others ordinarily concealed by the leaves. These hidden flowers are white or pale, lumpy, and closed. In certain districts in Italy, the same species of violet do not form these closed (cleistogamous) flowers. In the sunniest parts of California gardens the violets never form them. Other plants form cleistogamous flowers, but the number of these

species in different regions is very clearly related to the amount of sunlight. Northern Europe, New England and the northeastern part of the Mississippi Valley have less sunshine than the great western plateau, the Rocky Mountain region, Italy and California. There are some species of cleistogamous plants on the plateau and in the Rocky Mountain region; there are more on the two slopes of the Alleghanies and in Europe. Only a species or two have been found in central California, and these live in the dim light of virgin redwood forest.

Animal physiologists have not yet shown, I believe, that the breeding-seasons of animals generally mark the reaction of these animals to external influences. There is obviously every reason why birds should not mate till the rigors of a severe winter are over. The breeding-season of frogs and toads must coincide with the season of abundant water in ponds and pools. But I am inclined to believe that where there are no seasonal differences, or only very slight ones, in light, warmth, rainfall, there are only slight differences in the habits of plants and animals. Sea-urchins, for example, like many of the sea-weeds, have no regular breeding-seasons; the changes are slight in the water which nearly always covers them. On the other hand, land animals, subject to the more pronounced changes in their habitat, have their cycles of vital processes to correspond.

Light stimulates flowers to form; it stimulates the violet to develop one kind or another according to the amount of light. Light influences the growth of leaves and stems by its direction quite as much as by its amount. The direction from which light comes determines also where and how a plant part shall form. Vertical leaves, like those of onion and eucalyptus, are alike both structurally and superficially on the two sides. Horizontal or oblique leaves evidently differ on their two faces. Light has much to do with this difference. The reproductive stage of the fern is a small, flat, leaf-like plant, usually growing closely applied to the soil, its upper side lighted, its under side dark. If, for purposes of experiment, the light is made to come from below or from one side, instead of from above, the reproductive organs form, as before, on the side away from the light. They always form on the dark side, whether this is above or below, or more or less vertical. Light and not gravity is here the formative influence, stimulating the reproductive organs to develop and determining by its direction the side of the plant which shall bear them. Sometimes there may be a conflict of influences. If there is no dark side, because the plant is equally illuminated on both sides, the reproductive organs will form equally on the two sides.

If the direction of illumination determines where the reproductive organs of these small fern-plants form, may it not also influence the shape of the plants themselves? It may. There are many small leaf-like plants, allied to the mosses and ferns, growing against soil, or

bark, or rock. Their structure is dorsi-ventral. When these little plants first start, they are erect and cylindrical; the divisions of the fertilized egg-cell from which they spring are at right angles to the source of light. Presently, however, these little cylinders tip over and, the light still coming from above, they spread out at right angles to it. Thus the erect cylindrical form and radial structure soon give place to prostrate leafy form and dorsi-ventral structure. It is now known in at least one case, and suspected in many others, that if the little plants can continue to receive light symmetrically, their form will be correspondingly symmetrical. By slowly revolving them for months after sowing, so that they were equally illuminated on all sides in succession, I have obtained plants which were as cylindrical at the end of my experiment as in the early weeks. Where the illumination was equal, the structure was perfectly radial; where it was unequal, the structure was dorsi-ventral.

This matter of bodily form, different or like in two succeeding generations, depends upon the direction from which the light comes. If the offspring have a one-sided illumination, as their parents did, their form will be flat and prostrate like their parents; but if the offspring are symmetrically lighted, they will be symmetrically formed in spite of the difference from their parents.

So far as these experiments contribute at all to the solution of biological or sociological problems they do so by indicating that like influences produce like effects on the same substance, and that, although the substance may be the same, unlike influences will produce unlike results. They make us a little more confident that the child of vicious parents, if itself sound, can be made into a much more desirable citizen if brought under influences different and better than those surrounding and exerted by its parents.

The formative influences so far discussed produce normal and healthy effects. The deformative and pathogenic influences which affect human and other animal bodies have their parallels among plants. Besides the plainly marked plant-diseases due to such obvious parasites as borers, rusts, rots and mildews, there are influences no less real, although easily overlooked.

City life is unfavorable to plants. Atmospheric and soil conditions are either bad or not bad, they are never good. One need only pass along a street in which the gas-pipes have been exposed to know that the soil is more or less saturated with stale illuminating gas. The odor is offensive. Trees rooted in soil poisoned by large or small, but always continuous doses, of illuminating gas, do not thrive. Their leaves are never the full rich green of trees in the country, the foliage yellows early and many leaves fall. Add leaky electric wires, leaky sewers, and the putrefactions going on in fouled soil, and one realizes the cause of the chronic lack of vigor of street shade trees.

The trees in yards, gardens and parks are only somewhat better, they are not entirely well. An atmosphere polluted by the products of all our fuels except wood contains active poisons, not merely inconveniences. Because there is less soot in New York and San Francisco the inhabitants speak boastingly to their less fortunate friends in Chicago or St. Louis. But the smoke problem of cities is a problem of gaseous, not solid, emanations. Smoke-consumers, so-called, add to the bearableness of urban existence by reducing one disagreeable feature. They do not in any way affect the more serious ones. The sulphurous and chlorine gases, even sometimes fluorine, escaping from the chimney-tops of the office and factory buildings, and from the dwelling houses, of a city of diversified activities, affect human, animal and plant life. Certain wild plants which one would expect to see on the tree-trunks and stone walls in towns where the air is humid, are entirely absent. They have disappeared, in fact, from European cities since the use of coal became general.

If one would have a clearer view of what the effect of these gases is let him go where they are discharged in greater proportions into the air and note the effect on the native vegetation. Wherever smelters are in operation, treating sulphurous ores of copper, zinc, mercury, plants sooner or later disappear. Forest and farm suffer and finally become almost or quite valueless. This is simple poisoning, resulting, where the dose is great, in death.

The egg of a gall-fly laid in or in contact with developing tissues, hatching a grub which feeds and grows and excretes, becomes surrounded by a growth unlike anything else which the leaf or branch would develop, a growth of plant-tissue characteristic of the particular kind of plant and of the particular kind of fly. This developing tumor is the result of the presence of the grub, of the formative influence of this parasite. Similarly, the tubercles developing on the roots of many plants exhibit the formative influence of the worms or of the bacteria without which they would not start, much less develop, as they do.

The life-experiences of all living things, and even the things themselves, are the joint product of substance and circumstance. Some, if not all, of the substance is continuous, transmitted, from parent to offspring; some, but not all, of the circumstance attending this from the beginning to the end of its existence, is continuous. In the continuity of substance and circumstance lies the basis of the likeness of succeeding generations: in the difference of circumstance from time to time lies the basis of the difference which we see between offspring and parents. For circumstance is but Emerson's synonym for the evolutionist's word environment; and environment, on analysis, proves to be the sum of the formative influences.

TRAINING COLLEGE TEACHERS

By W. B. PITKIN
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YOUR American is quite willing to admit that his children, on commencement day, are not what they should be, but he is sure that he and his fellow taxpayers are not to blame. They support twice as many teachers as saloonkeepers. They have built all the machinery of education. Never were more kinds of schools, never better equipment. If, therefore, a college president were to sigh over the scarcity of good instructors, your American would not understand. He would say:

> You have your buildings and your professors and your students. You offer graduate work for all who would teach. You even have teachers' colleges. And I see many young men of exceptional attainments becoming college instructors every year.

And probably the college president, too, would join in his mystification, or—what amounts to the same thing—repeat "*nascitur non fit*," and fancy the shortage explained. But the machinery is not complete, as either party may discover when asked to point out the exact process of training college teachers. Suddenly it will appear that there is no such process.

Every other sort of teacher is being broken in. Normal schools are swiftly filling elementary and high schools with men and women who can manage not only their subjects but also their pupils. A teachers' college prepares its students

> for university and college professorships or instructorships in education; and for work as supervisors, principals and superintendents of schools, and as heads of academic or educational departments in normal and teachers' training schools; as well as professional training, both theoretical and practical, for teachers of both sexes for secondary, grammar and primary schools and kindergartens; and for special teachers of such technical subjects as domestic art, domestic science, fine arts, manual training, music, nature-study and physical education.

"Professorships in education," but no classes for ordinary professors who would educate! And so everywhere else. The university specialist is drilled for research and for the management of graduate classes during the years of his doctorate and later assistantship in laboratory or library. But where does the college teacher, the man who is to teach freshmen English and economics, pick up the tricks of his trade?

If he ever picks them up, it is by chance or cleverness and in spite of obstacles. The special knowledge he is to impart he gets well enough

—perhaps too well. The collegiate post is approached through the doctorate. In the later stages of this way, he is sometimes allowed to correct examination papers, lead quizes, and, if his professors are kind, even give a course of lectures. But usually this last boon is reserved for the days of assistantship, when, left to his own resources, he takes charge of a brawling roomful of sophomores. Of pedagogy knowing only the name, he sets about instructing by the method of trial and error; and the result is mostly trials and errors. The holy law of individualism locks the door against the professor who might be tempted to stroll into the beginner's class-room and help him along. But, if he were only left alone at his teaching, he might hope to pick up practical wisdom in a few years. He has not even that good fortune, though. If not by word, then by attitude, his colleagues often discourage him from becoming a "mere teacher." There is earnest in the old jest: "A college would be a fine place, but for the students." Our young instructor sees his seniors' names at the head of articles in his technical journals and they spell: "Go thou and do likewise!" At department conferences, problems of economy and research are broached, but beyond the broader question of schedules, text-books, periods and general manner of treatment, teaching is untouched: Is it because even the professor thinks his colleague *nascitur non fit,* and so dares not advise him for fear of insinuating that he is not fit? Be that as it may; pedagogy is suppressed as by a censor and investigation exalted until the university habit is set in grooves too deep to leave. And the freshman is left a foundling in inhospitable or palsied hands.

The results of this familiar unbalance are so grotesque that the writer, for one, would not believe them save on the evidence of his own eyes and ears. One instructor, whose researches have been a credit to his college, makes his freshmen learn the French for all parts of a full-rigged ship—and this, too, after he has taught several years. A scientist, with an important investigation half finished, turns his undergraduates into laboratory assistants; and, when confronted by a complainant committee, is honestly thunderstruck to hear that nobody is getting anything out of his courses. A mathematician of international repute lectures to his beginners on the great controversies of the geometers since Descartes. And a student assures me that, in the second semester of freshman German, he was set to translating "Macbeth" into the tongue of Goethe.

Let us not berate anybody for such absurdities, least of all the teachers themselves. Their pedagogical ignorance is due neither to slovenliness nor to neglect, but is a more or less inevitable incident in the great turmoil through which all our educational ideals, methods and means have been and still are passing. The hour calls less loudly for criticism than for a remedy. And the sky has cleared enough to

bring the latter into sight. Though the purpose of college may still be beclouded, and though there is still much fighting in the dark over the curriculum, at least two things are pretty sure: first, within fairly wide limits, it makes little difference what the undergraduate is taught in his first two years, provided he is really taught;[1] and, secondly, teaching is not a trick that any man can pick up for himself. These two facts leave us with only one thing to do—train graduate students to be college teachers.

Our normal schools and teachers' colleges have proved this possible. They are turning out excellent high-school teachers, and, if that can be done, then at least good teachers for the first two undergraduate years are makable. The difference between high school and college is narrowing. The National Association of State Universities, in its efforts to create a Standard American College, aims to "differentiate its parts in such a way that the first two years shall be looked upon as a continuation of and a supplement to the work of secondary instruction, as given in the high school." Let us restrict our problem, then, to the making of a freshman and spohomore faculty. If we can furnish this much, the rest will be easy.

There are many reasons why the normal school should not be called upon to do this for us; but the chief one is that the institution offers no opportunity for genuine apprenticeship. And without apprenticeship, training is greatly hampered, as the normal schools themselves have learned in the case of the high-school teacher. To the college, then, falls the training. The larger universities must offer it in a graduate school, and somewhat after the following manner.

1. A three-year course, of which one year shall be given over to pedagogy and two to actual teaching, shall lead to a doctorate. I trust the pedagogy needs no explanation. The two practise years, however, may. They find their defense in the axiom that the only way to learn how to teach is to teach. And they find their excuse in the fact that the young teacher is a necessary evil. An ideal college, to be sure, would have, say, a professor ordinary for every freshman class of fifteen; but not even Mr. Rockefeller is willing to finance such an institution. And not all the money in the world could make *all* college instructors finished scholars. So surely as teachers must be born and bred, just so surely must the undergraduate always suffer more or less from immature instruction. But he will suffer least if led by young men who are engrossed, not in writing a thesis, but in their class work.

The course of training I suggest should lead to a Ph.D. in order to attach the same dignity to the expert teacher that now attaches to the skilled investigator. This means, of course, a sharp break with tradi-

[1] Not that Choctaw is just as good as chemistry, but the lower levels of all grand divisions of knowledge lie in about the same plane.

tion. The doctorate has always stood for original work, discovery, scientific attainment. It has generally been assumed that these virtues are superior to those demanded of the man who at once imparts knowledge of a special sort and shows to growing minds its wider bearings for the building of character and the perfection of culture. This is, nevertheless, pure superstition; the sooner we smash it, the sooner will business and professional men cease to look down upon teaching, and the sooner have no ground for saying that the academic career attracts inferior men. Let us frankly rate teaching as a specialty on a par with those now pursued in graduate schools; it will prove not only just but, I think, excellent diplomacy.

2. The candidate for such a degree shall specialize in some general subject. His first year shall include the elements of teaching (if these have not been mastered in undergraduate courses), and also as much special drill in the pedagogy of his elected field as is feasible. If the university can not offer the latter, an arrangement might be made whereby the student could spend his first year at an institution where the work is provided. There is no reason, though, why, after the proposed system is inaugurated, one professor from each of the freshman and sophomore departments could not find time to offer such work.

3. When, in the second year, the student becomes a teacher in the department of his choice, he shall be assigned to *full teaching work*. Perhaps an ideal apportionment would be two freshman and two sophomore sections of fifteen students each in three-hour courses, making a total of twelve hours' classwork a week. Half this amount might be preferable in the first semester of teaching. At least one professor in the department shall devote part of his time to supervising the student-teachers. He shall visit the sections as often as he deems necessary. He shall question the student-teachers about the individual men in their classes and their difficulties. At the close of each semester, he shall examine the sections himself; and his marking shall be counted in upon the term marking both of students and their student-teacher on some equitable fractional basis. (For instance, the supervisor's markings might weigh equally with the term markings of the student-teacher against the student; and the supervisor's average marking of the class might weigh equally with the student-teacher's individual knowledge of his subject in the computation of the student-teacher's total efficiency. These proportions are, of course, merely illustrative.)

4. The student-teacher shall be required to attend no classes in his last two years of work; but, he may have the privilege of so doing; if, in the opinion of the department, he will profit thereby. In general, however, the policy of the department should be to encourage wide reading, not only in his specialty but in cognate branches, the aim always being to give him his bearings in the world and make him

see things in such a perspective that he may speedily become a competent adviser.

5. If after two years of teaching, the student-teacher shall have convinced the professors of his department that he has mastered his subject satisfactorily and has developed sufficient teaching ability and has shown a character suitable for the calling, he shall be awarded the degree of Ph.D. The degree shall be given in whatever subject the recipient has taught. The method of determining ability may vary considerably, no doubt; but some combination of examination ratings and "general impression" should be struck, in any case. The student-teacher receiving such a degree shall be placed upon a preferred list of candidates for recommendation to college appointments.

What, now, are the advantages of this system?

1. It will provide the best possible young teachers. Under any system the young teacher is a necessary evil; but he is the least troublesome when wholly devoted to his class-work. And he is most completely devoted to it when in it he finds the way to a higher degree and to advancement, and when he knows his success or failure *as a teacher* is being checked up on his score-card.

2. It will permit the nearest practicable approach to individual teaching. The supreme difficulty in the way of individual teaching is the cost. Some day one or two of our richer colleges may hope to have a staff of mature men large enough to give every student a faculty adviser and a private tutor; but most schools must resign that prospect. The next best thing, however, is the small class with closely supervised instructors who are teaching without pay (or on small scholarships) in the hope of an advanced degree and preferment.

Let us see how nearly the goal may be approached. Imagine a very large college whose freshman class is, say, 1,000. Suppose one course of English is required in each semester of the first year. The English department will then have all these 1,000 students to deal with. Suppose there are in this department altogether, 12 professors and instructors (Harvard has at least 5 more, not counting her assistants). And let us assume the purely ideal condition of having a student-teacher manage only 2 sections of 15 students each. Suppose, on the other hand, that neither of the required freshman courses could be partly or wholly given by lecture. We should then have the ideal arrangement fulfilled, if each of the 12 instructors took only one freshman section and were assisted by 27 student-teachers. By increasing the class unit to 20 students, only 19 student-teachers would be called for. Does anybody imagine that a university with a college entering class of 1,000 would have much difficulty in securing nearly that number of student-teachers for at least each of the five chief departments under the terms of the system we have sketched?[2] Needless to say,

could only half the ideal number of student-teachers be secured, undergraduate instruction could still be revolutionized; if in no better way, then by putting half the students in small sections one semester, and the other half there the next. With a little careful adjusting of schedules, most students would then receive close attention in two of four departments each semester.

3. It would not add one dollar to the annual budget, but, on the other hand, would actually reduce the latter by a considerable sum, inasmuch as many assistants could be dispensed with. It is impossible to compute accurately here, for the necessity of assistantships varies greatly from department to department. In the natural sciences, for instance, laboratory helpers will always be needed, however many student-teachers there are. But, in the freshman and sophomore work, the assistants in most of the departments only correct papers, hold quizes, etc.—all of which could as well be done—and better—by the student-teacher, who would have time for it and ought to learn it. If, now, we assume that only half of the assistants now employed in our leading colleges are doing such work, we shall find that our system would reduce the yearly running expenses of Brown by $2,522, those of California by $14,025, those of Harvard by $7,808, those of Chicago by $9,990, and those of Columbia by $17,500. These estimates are based upon the number of assistantships and the average salaries of the same as given in the second bulletin of the Carnegie Foundation. Half of these savings, devoted to small scholarships for worthy student-teachers, would doubtless help materially in maintaining the quality of candidiates. Part of the other half, added to the salary of those professors who supervised the staff of student-teachers, would stimulate competent men to turn from research and graduate teaching to education. At universities with good pedagogical departments, not a single new chair would have to be created; the general pedagogical work of the student-teacher's first graduate year is already offered, while the special courses for history teaching, mathematics teaching, etc., may be given by the already installed professors of these subjects. Probably every university of rank has, in each department, at least one man who can give such courses. He is, I fear, often inconspicuous, thanks to the overshadowing discoveries and books of his colleagues; but he can, for all that, be found and turned into his proper work.

4. It will hasten the differentiation between college and university. And, while these two institutions are still "siamesed," it will provide

[2] As closely as I can estimate from the Harvard catalogue, individual training in English could be given at Cambridge, if the present staff were augmented by only 25 student-teachers, and the 11 assistants now employed dispensed with. Were the latter converted into student-teachers, the department would have to find only 14 more graduate students, in order to fulfil the very severe conditions named.

for the fairer division of effort and attention between them. Student-teachers will relieve some members of the faculty from elementary work; it will let others pass over completely into the graduate schools in the course of time. After ten years, a respectable number of student-teachers will be ready to fill purely collegiate professorships.

5. While effecting this differentiation, it will also unify college life. If it does nothing else, it will clarify the aim and policy of each department simply by concentrating attention upon teaching problems. But it may also lead to a more thorough system of faculty advisers than has yet been found feasible. There is no reason why a student-teacher, at least in his third year, could not profitably serve as personal counselor for a few undergraduates. At present, as is generally known, the faculty adviser rarely does more than talk at long intervals with his protégés, and then on nothing more than the narrower questions of electing courses. He has no time for intimacies, as he usually carries from 14 to 16 hours of lectures a week, and has from a dozen to a score of students assigned to him. If, however, there could be an instructor for every thirty or forty students in *each* of the five chief undergraduate departments, then only six to eight students would have to be assigned to a single adviser.

6. It will help bridge the gap between high school and college. A common and well-grounded complaint to-day is that college teachers are not drawn from the ranks of the better high-school teachers. The trouble has not been with the latter; there has simply been a tradition that a college teacher must be a Ph.D. and a scientific investigator—and few high-school teachers have ever entered either of these select circles. Give the doctorate, though, for mastery of college teaching; and two things will eventually happen. First, many student-teachers upon receiving their degree, will be unable to secure college posts; and so they will then turn to high-school work, against which they will not be prejudiced, as your ordinary Ph.D. is to-day, and for which they will naturally be preferred candidates. Secondly, student-teachers thus installed will not be rooted forever to their high school, for they are known to college professors; they have taught two years in college and have established something of a reputation there which will help the best of them into college chairs some day. It is also possible that a small movement from high school to college will be set up by high-school teachers leaving their work to try for the Ph.D. in the hope of getting permanently into college work. During the next decade, this movement might be considerable, were the student-teacher system generally adopted. There are many excellent teachers in high schools who could teach freshmen and sophomores infinitely better than half the young *doctores eruditissimi* now thus engaged. And among the younger of them quite a few would prefer college to high school so strongly that they would be tempted to become student-teachers.

7. It will so improve the first two years of undergraduate work that students will be much better prepared to take up courses leading to professional and graduate pursuits in their junior year. And this is what many educators, together with the National Association of State Universities, wish to bring about.

Several objections to this plan are already on the reader's lips. It will make the doctorate equivocal. It will remove the professor from the freshman, who really needs him most. Nobody will try for such a doctorate. Or, maybe the opposite; every senior anxious to get a job will rush into this line, and there will be no candidates for research. With all the younger students under young men, discipline will become lax. A student only five years beyond his freshman days can not teach freshmen. To all these and many more, I think, good answer may be given. In the meantime, if we admit that some project for training college teachers is urgently needed, this one recommends itself to trial because it can be put fairly well to the test *without cost, without change of curriculum,* and, if necessary for prudence's sake, *in only one department.*

OKEFINOKEE SWAMP

By ROLAND M. HARPER

TALLAHASSEE, FLORIDA

OKEFINOKEE Swamp, which covers about 700 square miles of territory on the southern borders of Georgia, is one of the least known areas of its size in the eastern United States. Its existence has indeed been known to white men ever since the eighteenth century, but very few persons capable of giving an intelligent account of it have ever explored it.

History

The earliest description of this swamp which we have is that of William Bartram. He never saw it himself, but passed near it in the spring of 1773, and seems to have gathered considerable information about it from the Indians and traders. In his celebrated volume of "Travels," published in 1791, we find the following description, which is such a curious mixture of truth and legend, and withal of so much historic interest, that it is worth quoting verbatim:

> The river St. Mary has its source from a vast lake, or marsh, called Ouaquaphenogaw, which lies between Flint and Oakmulge rivers, and occupies a space of near three hundred miles in circuit. This vast accumulation of waters, in the wet season, appears as a lake, and contains some large islands or knolls, of rich high land; one of which the present generation of Creeks[1] represent to be a most blissful spot of the earth; they say it is inhabited by a peculiar race of Indians, whose women are incomparably beautiful; they also tell you that this terrestrial paradise has been seen by some of their enterprising hunters, when in pursuit of game, who being lost in inextricable swamps and bogs, and on the point of perishing, were unexpectedly relieved by a company of beautiful women, whom they call daughters of the sun, who kindly gave them such provisions as they had with them, which were chiefly fruit, oranges, dates, &c., and some corn cakes, and then enjoined them to fly for safety to their own country; for that their husbands were fierce men, and cruel to strangers: they further say, that these hunters had a view of their settlements, situated on the elevated banks of an island, or promontory, in a beautiful lake; but that in their endeavors to approach it they were involved in perpetual labyrinths, like inchanted land, still as they imagined they had just gained it, it seemed to fly before them, alternately appearing and disappearing. They resolved, at length, to leave the delusive pursuit, and to return; which after a number of inexpressible difficulties, they effected. When they reported their adventures to their countrymen, their young warriors were enflamed with an irresistable desire to invade, and make a conquest of, so charming a country; but all their attempts have hitherto proved abortive, never having been able again to find that enchanting spot, nor even any road or pathway to it; yet

[1] According to Dr. William Baldwin, Bartram confused the Seminoles with the Lower Creeks.

they frequently meet with certain signs of its being inhabited, as the building of canoes, footsteps of men, &c. . . .

It is, however, certain that there is a vast lake, or drowned swamp,[3] well known, and often visited both by white and Indian hunters, and on its environs the most valuable hunting grounds in Florida, well worth contending for, by those powers whose territories border upon it. From this great source of rivers,[5] St. Mary arises, and meanders through a vast plain and pine forest, near an hundred and fifty miles to the ocean, with which it communicates, between the points of Amelia and Talbert[6] islands; the waters flow deep and gently down from its source to the sea.

About this time the swamp began to appear on maps, though often located far from its true position, and with the name spelled in a wonderful variety of ways. On old maps of Georgia preserved in the Library of Congress the following variations in spelling can be found: Ekanfinaka (1790), Akenfonogo (1796), Eokenfonooka (1810), Oquafanoka (1818), Oke-fin-o-cau (1818) and Okefinoke (1831). The last agrees pretty well with the pronunciation used by people living in the immediate vicinity at the present time, who commonly speak of the swamp as "the Okefinoke" (leaving the e's silent or nearly so). The name is said to be derived from Indian words meaning "trembling earth," alluding of course to the boggy nature of the swamp.

After Bartram nothing of importance seems to have been learned about this swamp for three quarters of a century. Dr. William Baldwin, the botanist, who resided at the nearest seaport, St. Mary's, from 1812 to 1814, wrote to his friend Dr. Muhlenberg, of Pennsylvania, on February 26, 1814, of having just been on a short botanical tour which "extended to within about twelve miles of the celebrated Okefanoka Swamp, at the head of St. Mary's" River, but he seems never to have approached it any closer than that. The description in Rev. George White's valuable "Statistics of the State of Georgia," published in 1849, is copied from Bartram, the principal difference being that the name of the swamp is there spelled Okefinocau. The boundaries of the area, however, are located more accurately on White's map than on some of later date. In "Historical Collections of Georgia," by the same author, published in 1855, is a shorter description of the swamp, from the same source, and the name of it is spelled "E-cun-fi-no-cau."

Probably the first white men, other than hunters, to explore the Okefinokee were Gen. John Floyd and his soldiers, who are said to have

[3] At this point in the German edition (published in Berlin in 1793) the editor, E. A. W. Zimmermann, inserts the following footnote: "Dieser Sumpf ist unstreitig der *Ekanfonoka Swamp* unter 30° der Breite; er nimmt aber auf Purcel's Karte mehr als Einen Grad ein."

[5] (Bartram's footnote.) "Source of rivers. It is said, that St. Ille [Satilla], St. Mary, and the beautiful river, Little St. Juan [Suwannee], which discharges its waters into the bay of Apalachi, at St. Mark's, take their rise from this swamp."

[6] "Talbert" is a mistake. He should have said Cumberland, as Dr. Baldwin pointed out about ninety years ago.

crossed it in pursuit of Indians during the first Seminole War, in the second decade of the nineteenth century. One of the islands in the swamp now bears the name of this general.

In the winter of 1856–7, Col. R. L. Hunter, an engineer, employed by the state of Georgia, ran a line of levels around the swamp to ascertain the practicability of draining it, and found its edges to range from about 110 to 126 feet above sea-level. This survey is said to have cost the state $3,260. His report to the governor, accompanied by a map, was filed away and almost forgotten, until unearthed in 1875 by Col. E. Y. Clarke, at that time editor of the Atlanta *Constitution*.

During the latter part of the Civil War, a number of deserters from the Confederate army found a safe retreat in the Okefinokee, and they are said to have lived for some time on an island (or perhaps a peninsula?) in the southeastern part of the swamp, which is known to this day as Soldier Camp Island.

Paul Fountain, an English traveler, claims to have been the first naturalist to visit this region. In his book, "Great Deserts and Forests of North America," published in 1901, he devotes 23 pages to it, and says among other things: "The Okefinoke has not, I think, been often penetrated; it certainly had not at the time I visited it in 1871 and 1876." Judging from the way he uses the name, he must have been pretty close to the place, but the chances are that he never saw the real Okefinokee Swamp at all. About half of his chapter on it consists of general remarks on snakes and other reptiles, and the remainder purports to be a description of the swamp; but this description differs considerably from those of all other explorers, and would apply much better to the swamp of the Suwannee River, which flows out of Okefinokee toward the southwest. Even with this interpretation, however, his remarks about the insalubrity of the region seem to be considerably overdrawn.

The first expedition for the systematic exploration of the Okefinokee wilderness was organized in the fall of 1875, by the Atlanta *Constitution* in cooperation with the state geological survey. The members of this expedition were the State Geologist, Dr. George Little, his assistants, R. H. Loughridge and C. A. Locke, Col. E. Y. Clarke and Mr. E. R. Hyde, of Atlanta, Col. C. R. Pendleton, of the Valdosta *Times* (now editor of the Macon *Telegraph*), two or three gentlemen living near the swamp, and a cook, guide and laborers. The "Constitution Expedition" remained in and around the swamp for six weeks, in November and December, 1875. A brief account of their work appeared in the report of the state geologist for that year, and a more extended description in Janes's "Handbook of Georgia," published by the state agricultural department in 1876. A few timber specimens secured by this expedition, together with several from other parts of Georgia, formed part of the state's exhibit at the Paris exposition in

1878, and a list of them in a pamphlet describing this exhibit seems to be the first authentic botanical information about the swamp ever published. The descriptions of this region in Dr. Loughridge's report on cotton production of Georgia, in the sixth volume of the Tenth Census, are derived from the author's connection with the same expedition.

Several years later, at a time when public interest in everything pertaining to the Okefinokee was heightened by circumstances to be mentioned below, Mr. Louis Pendleton, brother of Col. C. R. Pendleton, combined the historical incident of the deserters with his brother's experiences in the swamp into a story quite true to life, entitled "In the Okefenokee," which was published in six chapters in the *Youth's Companion* in August and September, 1894. (In the same paper a year later there appeared a short story entitled "Life in the Okefenokee," which must have been written by some one who had never seen the swamp.)

Until the last decade of the nineteenth century the greater part of Okefinokee Swamp was included in the public lands of Georgia, never having been claimed by private parties. In 1889 the legislature decided to dispose of the state's remaining interest in it, and in March, 1890, it was sold for 26½ cents an acre to a syndicate organized for the purpose, headed by Capt. Henry Jackson, of Atlanta, and styled the Suwanee[5] Canal Company. This company's purchase from the state amounted to about 380 square miles, and the remainder of the area was gradually acquired from private parties who held it. The object of this company was primarily to convert the timber in the swamp into cash, and the necessary surveys having been made, work began in the fall of 1891. From Camp Cornelia (named after Capt. Jackson's daughter), near the middle of the eastern margin of the swamp, a canal about 45 feet wide and 6 feet deep was gradually cut by dredges, working day and night by the aid of electric search-lights, and progressing toward the middle of the swamp (see map) at the rate of about three miles a year. At the same time an enormous ditch was dug from the same place to the nearest point on the St. Mary's River, about six miles away, by which it was intended first to float logs out to the river and finally to drain the swamp. This ditch was practically completed by 1894, but the company then found it more feasible to erect a sawmill at Camp Cornelia and ship the sawn lumber, by a railroad constructed for the purpose, to Folkston on the Savannah, Florida & Western Railway (now Atlantic Coast Line) and Bull Head Bluff on the Satilla River.

While this work was going on Capt. Jackson visited the Okefinokee about once a month, sometimes staying a week or more at a time, and

[5] Suwannee is usually spelled with two n's, but in the official designation of this company it had only one.

exploring it pretty thoroughly. He is said to have had a more extensive knowledge of it than any other man living. As a result of his activity a good deal of information about this interesting place was spread before the public, in newspapers and otherwise. The best accessible description of Okefinokee Swamp, in Nesbitt's "Georgia, her Resources and Possibilities," published by the Georgia agricultural department in 1896, is based on his observations. Most of the above history of the operations of the Suwanee Canal Company is taken from this book, and is given in considerable detail here because the book seems to be quite rare. An abridged description can be found in Stevens & Wright's "Georgia, Historical and Industrial," a similar but much larger book published by the same department in 1901, and in Bulletin No. 5 of the Geological Survey of Georgia, by S. W. McCallie.

After the death in 1895 of Capt. Jackson, its president and most active member, the canal company suspended operations. The ten or twelve miles of canal and five or six miles of drainage ditch began to fill up with vegetation, the steamboats and dredges mostly sunk or were burned, the sawmill fell to decay, and the rails of the logging road were taken up. The property then passed into the hands of some northern lumbermen, who it is said are still planning to exploit the economic resources of the swamp, though there was no visible evidence of their work at the time of the writer's visit a few years later.

To return to the progress of exploration of the Okefinokee; Dr. Filibert Roth, at that time connected with the Division of Forestry of the U. S. Department of Agriculture, seems to have made a brief visit to the swamp in the spring of 1897. Incidental references to the two commonest trees of the swamp, cypress and slash pine, were published by him soon afterwards in Bulletin 13 (revised) and Circular 19 of the Division of Forestry.

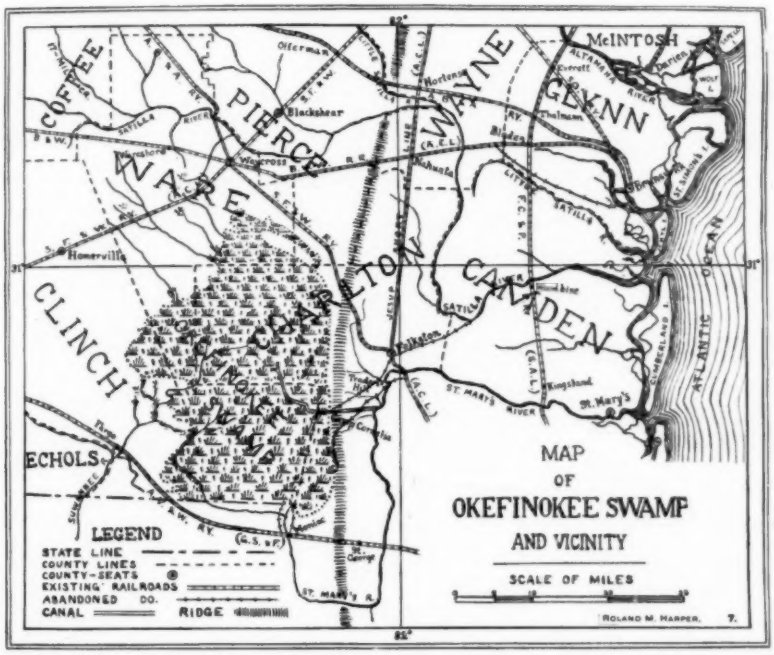
In August, 1902, the writer, in the course of botanical explorations in south Georgia, spent two days in the swamp, and considerably more time in the surrounding country. In the swamp he was accompanied by Mr. P. L. Ricker, of the U. S. Department of Agriculture, and a native guide. We traversed the whole length of the old canal in a small boat, and made a side trip on foot through the bogs to an island about two miles off the canal. Together we took about forty photographs, including all those used to illustrate this article. Brief notes on this expedition have been published in several scientific journals, but nothing like a complete description of the vegetation of the swamp has yet been attempted.

During the winter and spring of 1905–6 a party from the Bureau of Soils of the U. S. Department of Agriculture examined the soils around Waycross, and in their report, published in April, 1907, is a pretty fair description of the northern end of Okefinokee Swamp.

Having outlined the sources of our knowledge of this interesting region, it may now be described from a geographical standpoint.

GEOGRAPHY

Okefinokee Swamp lies almost entirely in Ware and Charlton counties, Georgia, about fifty miles from the coast and 115 feet above sea-level. (It will be noticed that in its elevation and distance from the



MAP OF THE SOUTHEASTERN CORNER OF GEORGIA, showing the location of Okefinokee Swamp and the ridge east of it. Compiled from county maps in the Secretary of State's office in Atlanta, a map drawn for the Suwannee Canal Company in 1897; U. S. Coast Survey chart No. 157, 1901; field notes of the author, 1902–1904; Rand, McNally & Co.'s map of Georgia, 1906, and the U. S. Department of Agriculture soil map of the Waycross area, 1907.

The abandoned railroads are shown principally because they are convenient highways for exploring the almost trackless pine-barrens on foot. The location of the islands and other details within the swamp are not given here because too little is known about them at present.

coast it differs considerably from the two other great swamps of eastern North America, namely, Dismal Swamp and the Everglades.) The surrounding country belongs to the flat pine-barren region of the coastal plain, and is notable for the lack of diversity in its topography. Except in the vicinity of some of the creeks and rivers, the ground has scarcely any slope, and the channels of the smaller streams are ill-defined. At almost any point on a railroad within thirty or forty miles of the swamp one can see the rails stretching away in a straight line farther than the eye can reach, in one or both directions. The longest

stretch of straight track in Georgia, from a few miles southwest of Waycross to a few miles beyond Valdosta, sixty miles in all, crosses the head-waters of the Okefinokee.

The geology of this flat pine-barren region is comparatively simple. The surface is a few inches or a few feet of Columbia sand, and under that is the clay, loam or coarse sand of the Altamaha Grit or Grand Gulf formation to a depth of three or four hundred feet. None of these formations are fossiliferous, but they are believed to be quite recent, probably of Pliocene or later age. Under them is a limestone believed to be Miocene, and below that presumably all the older coastal plain formations in succession. There is every reason to believe that the whole swamp is underlaid by the same formations, from the Columbia down.

Immediately east of the Okefinokee is one of the most interesting topographic features of the region, which would scarcely be noticeable but for the general flatness of the country. It is a broad low ridge, exactly parallel with the coast and just about forty miles distant from it. This ridge has been traced by the writer from a few miles west of Jesup southward into the great bend of the St. Mary's River, and about thirty miles into Florida, where it is known as the "Trail Ridge," and happens to coincide in part with the Atlantic and Gulf divide and with the eastern boundary of Baker and Bradford counties, though still maintaining its parallelism with the Atlantic coast. It is not an important divide in Georgia, though no streams intersect it between the St.

ABANDONED DRAINAGE DITCH NEAR CAMP CORNELIA.

Mary's and the Altamaha except the Satilla and Little Satilla Rivers.

At Camp Cornelia, where the old drainage ditch of the Suwanee Canal Company cuts through it, this remarkable ridge is about two miles wide and only about forty feet high; and it probably keeps practically the same dimensions for many miles north and south. Its slopes are so gentle as to be scarcely noticeable to a person passing over it, but when viewed from a point a few miles away on one of the straight railroads which cross it it stands out quite conspicuously.

INTERIOR OF JACKSON'S BAY.

Trail Ridge, or Okefinokee Ridge, as the Georgia end of it might be called, does not belong to the class of *cuestas* or inland-facing escarpments which can be seen in many places in the upper half of the coastal plain, for it slopes equally on both sides and has no stream hugging its inland edge as far as known. Moreover, it is too smooth and too straight to have been formed by erosion. The most reasonable explanation of it would seem to be that it marks a comparatively recent slight flexure of the earth's crust, formed during one of the oscillations which the coastal plain experienced several times during its making. There seems to be a similar though smaller ridge about fifteen miles east of it, but so little is known about that that it could not be mapped at the present time. Mount Pleasant and Waynesville, near the boundary between Wayne and Glynn Counties, are located on the latter ridge, and along its summit was one of the principal roads from Savannah to East Florida a century ago, followed by Bartram and other travelers.

The internal structure of the Okefinokee Ridge is not its least interesting feature. In the big ditch at Camp Cornelia, as well as at the crossings of four railroads (three of them shown on the map and one a little farther north), there occurs beneath a few feet of white sand a chocolate-colored or almost black material of unknown depth, known locally as "hardpan." No analysis of the hardpan is available, but when pulverized in the fingers it feels like nothing but sand. Its dark color is doubtless due to vegetable matter, with a little cement of iron oxide or bog iron ore, which makes it so hard in the mass that dynamite

JACKSON'S BAY (outer edge).

was used in removing it, it is said. No recognizable organic remains were noticed in it, but a faint horizontal stratification could be detected. The aspect of the hardpan is so similar to that of the subsoil of existing salt marshes that its origin is not hard to guess.

Although this peculiar formation may not be confined to the Okefinokee Ridge, its extent is evidently limited; for in railroad cuts around Waycross and Folkston and in Camden County and elsewhere the ordinary reddish Pliocene loam can be seen near the surface, without any signs of the black hardpan. The hardpan was doubtless formed in some prehistoric swamp or marsh occupying a somewhat larger area than Okefinokee does now—perhaps the "Suwannee Strait" of geologists,[6] which is supposed to have separated Florida from the mainland in Miocene times. It seems to have no effect on the vegetation above it, which is just like that of the ordinary flat pine-barrens underlaid by the loam.

[6] See Dall, Bull. U. S. Geol. Surv., 84: 111, 121–122, 126, 1892.

Assuming the foregoing theories to be true, we can now trace the probable development of Okefinokee Swamp. When the ridge was thrown up across the shallow trough which had been Suwannee Strait it naturally created a basin behind it, which must have quickly filled with water, forming a large shallow lake. This lake then began to fill with vegetation, as many other shallow lakes and ponds in temperate regions are doing, and gradually took on the aspect it has to-day, which will be described more in detail below, under the head of vegetation. A glance at the map will show how the waters are dammed up by the ridge, the straight eastern border contrasting with the very irregular western border of the swamp.

The drainage of the region presents some peculiar features. Okefinokee Swamp is approximately on the watershed between the Atlantic Ocean and the Gulf of Mexico. In dry weather the Suwannee River seems to be its only outlet, but at other times some of the water may be discharged into the Atlantic through the St. Mary's. Being about on a watershed, the drainage area of the swamp is rather small, including only a few hundred square miles outside of the swamp itself. Its tributaries are practically confined to Ware County, on the northwest, and none of them exceed twenty miles in length. As the swamp is a few hundred feet vertically and a good many miles horizontally from any limestone, subterranean inlets and outlets are out of the question.[1] The color of the water in the swamp and in all the streams in the vicinity shows it to be entirely free from lime as well as from mud.

The courses of the Satilla and St. Mary's Rivers in the neighborhood of the swamp are rather peculiar. Each after passing through the Okefinokee Ridge turns and flows parallel to the coast for about thirty miles, in the trough between the two low ridges mentioned, and then resumes its eastward course to the sea. The circuitous channels of these rivers must have been formed at the time of the Columbia submergence of the coastal plain if not before, for in such a flat sandy country there is practically no erosion going on at the present time, and such phenomena as stream-capture are unknown.

Climate

A pretty accurate estimate of the climate of the Okefinokee can be obtained by taking the averages of the figures for Waycross, Ga., and Macclenny, Fla., which lie on opposite sides of the swamp and at about the same distance from the Atlantic coast. Summed up by seasons, the average temperature and total rainfall are as follows:

[1] Paul Fountain, in his book previously referred to, described a large limestone spring in the "northern part" of Okefinokee, but in all probability this spring was on the Suwannee River somewhere in Florida, where such things are rather common.

Seasons	Spring (March–May)	Summer (June–Aug.)	Autumn (Sept.–Nov.)	Winter (Dec.–Feb.)	Annual
Temperature (degrees Fahrenheit).....	68.4	81.6	69.3	52.3	67.9
Rainfall (inches).....	10.0	19.5	9.8	10.7	50.0

Frost usually occurs in four or five months of every year, but snow is rare. The maximum temperature here, as nearly everywhere in the eastern United States outside of the mountains, is about 100°. It is noteworthy that nearly two fifths of the total annual rainfall comes in the three summer months, as seems to be the case all over the southern half of Georgia. August is the wettest month, with about 7 inches of rain, and November the driest, with a little less than 2. The total annual amount happens to be a little less than the average for either Georgia, Florida or Alabama.

Vegetation of the Swamp

The various aspects of different parts of Okefinokee Swamp seem to depend almost entirely on the distance of the sandy bottom

Bugaboo Island.

below or above the water level. Areas where the sand rises above the water constitute the islands. There are about half a dozen of these, Floyd's Billy's, Mitchell's, Black Jack, Honey and Bugaboo, with areas ranging from about one to ten square miles. The largest islands are naturally highest and driest, and are said to bear a fine growth of long-leaf pine (*Pinus palustris*), and perhaps some oaks and hickories. The only island which Mr. Ricker and the writer were able to reach (on account of the low stage of water prevailing at the time of our visit,

the rainfall that month having been only about half the normal for August) was Bugaboo Island, one of the smallest. Its surface seems to be elevated only a foot or two above the surrounding swamp, and its edges slope off so gradually that one can not tell within several rods just where swamp ends and island begins. Nine tenths or more of the trees on this island are slash pine (*Pinus Elliottii*), a species common in low or flat pine-barrens all over southeastern Georgia. The rest of the trees are mostly black pine (*Pinus serotina*), and the under-

SPHAGNUM BOG WITH PINES AND FERNS.

growth consists of saw-palmettos (*Serenoa*) and several other low evergreen bushes, much as on the neighboring mainland. There is almost no grass on the island, probably on account of the rarity of fires, which outside of the swamp keep the bushes in some measure suppressed.

Bugaboo Island (and probably most of the others) is surrounded by sphagnous bogs, which resemble the northern tamarack and cedar swamps in many ways. The trees in the bogs are conifers, one evergreen, the slash pine already mentioned, and one deciduous, the cypress (*Taxodium imbricarium*); analogous to the evergreen spruce and deciduous tamarack of the northern bogs. (The white cedar or juniper, *Chamæcyparis*, the only water-loving conifer common to the glaciated region and coastal plain, is not certainly known to grow in Okefinokee, but the chances are that it grows there just as it does in Dismal Swamp and many of the swamps of Florida.) Beneath the trees, which grow rather openly, the vegetation consists of heath-like shrubs, ferns

(mostly of one species, *Woodwardia Virginica*), sedges, sundews, pitcher-plants, etc. The pitcher-plants (*Sarracenia minor* and *S. psittacina*) grow two or three times as large in Okefinokee as they do anywhere else. The leaves of *S. minor,* which had never been known to grow more than a foot tall in the pine-barrens, often attain a height of over three feet in the swamp. The ground in these bogs is everywhere covered with a dense soft carpet of sphagnum.

Where the swamp muck has reached a depth of three or four feet the pines can no longer exist, and the cypress grows much more densely than it does in the bogs, constituting the bulk of the vegetation. Such places are known locally as "bays." There the long moss (*Tillandsia usneoides*) drapes every tree, though it never grows as luxuriantly as in calcareous or alluvial regions in the same latitude. The shrubs, herbs and mosses in the bays are much the same as in the bogs already described, though considerably less abundant. One shrub deserves special mention on account of its peculiar habit. It is *Pieris phillyreifolia,* a handsome little evergreen of the heath family, confined to Georgia, Florida and Alabama. It sometimes stands erect, two or three feet tall, but usually it starts at the base of a cypress tree, and its stems insinuate themselves between the inner and outer layers of the bark of the tree, gradually working upward to a height of thirty or forty feet from the ground, and sending out branches with leaves and flowers every few feet. Growing in this way the shrub might easily be taken for a parasite, but its stems can always be traced down to the ground, and they bear no rootlets and never penetrate to the living part of the bark. As far as known this manner of climbing has no parallel in the whole vegetable kingdom.

Where the sandy bottom of the swamp lies six feet or more below the average water level no trees can grow, and we have what are known as "prairies." The prairies are all in the eastern half of the swamp, where their aggregate area is perhaps as much as a hundred square miles. In wet weather the water covers them so that one can go almost anywhere in a shallow boat, especially by following the "'gator roads," or trails made by the alligators; but when the water is low the prairies are impassable for boats while still too boggy to walk in. This being the case at the time of our visit we could only view them from the banks of the canal. The bulk of the vegetation in the prairies consists of "maiden cane" (*Panicum digitarioides*),[8] interspersed with "fire-leaf" or "bull-tongue" (*Orontium aquaticum*), "wampee" or pickerel weed (*Pontederia*), white water-lilies (*Castalia*), and numerous other characteristic aquatic plants. There seems to be no sphagnum, perhaps because it will not grow without shade in that latitude. The

[8] The true cane (*Arundinaria*), which is said to be very abundant in Dismal Swamp, seems to be entirely absent from Okefinokee, as it is from the Everglades.

prairies seem to have no counterpart in Dismal Swamp, but they look very much like some pictures of the Everglades.

The prairies are dotted here and there with small clumps of cypress trees and evergreen vines and bushes, known as "houses," from the fact that hunters sometimes camp in them while in the swamp. These probably represent shallower spots, or incipient bays.

In some of the prairies are considerable bodies of open water, known to the natives as lakes. These doubtless mark the deepest parts of the swamp, not yet filled with vegetation. They are comparatively shallow though, the combined depth of water and muck perhaps nowhere exceeding ten feet.

CHASE'S PRAIRIE.

ANIMAL LIFE

As Okefinokee Swamp has probably never been visited by a zoologist, no reliable account of its fauna can be given here. Bears and deer are still found on the islands, and occasionally stray outside of the swamp. An old hunter living at the north end of the swamp, when interviewed by a correspondent of the Atlanta *Constitution* in the spring of 1897, estimated that in the forty years he had lived there he had killed about 150 bears, 200 deer, and hundreds of wolves, minks and wildcats. In the summer of 1900 there was an item in the same paper to the effect that a large black bear had been seen at Manor, about ten miles northwest of the swamp, and caused great consternation among the negroes employed in the turpentine orchards there. Early in 1907 a bear was seen several times near Adel, in Berrien County, about sixty miles farther west, and Col. C. R. Pendleton, commenting on it in his paper,

the Macon *Telegraph*, expressed the opinion that it had come out from Okefinokee by way of the swamps of the Suwannee and Withlacoochee rivers. At the time of our visit to the swamp our guide showed us on Bugaboo Island a fresh scar on a pine tree about five feet from the ground, where it had been gnawed or scratched by one of these animals. Other mammals reported from the swamp by the Constitution Expedition and Capt. Jackson, besides those already mentioned, are otters, 'coons, panthers and squirrels. In the line of birds we noticed especially a number of egrets (?), a water-turkey, and the nest of an eagle. Owls, ducks and geese were reported by the Constitution Expedition, white and blue herons and curlews were mentioned by Capt. Jackson, and Gannet Lake and Buzzard Lake, in the southern part of the swamp, probably indicate the occurrence of birds similarly named. The commonest reptiles are alligators, which sometimes attain a length of twelve feet, according to several authorities, but they are now much scarcer than formerly, owing to the depredations of hunters who seek their hides, and we saw only one live one. Snakes are not very numerous, and only one of them (a water-moccasin) was encountered in the two days we were in the swamp. "Yellow-belly terrapins" are also found there, it is said, and are sought after to some extent for their flesh. Fishes mentioned by Capt. Jackson are large-mouth black bass or "trout," weighing six to twelve pounds, and jackfish, up to ten pounds. A small specimen of the latter jumped into our boat one afternoon, and formed part of our next meal. The only insects which gave us any trouble were mosquitoes, and those only at night.

Inhabitants

The greater part of the Okefinokee is of course unsuitable for human habitation, but the islands are known to have supported a small if not permanent population. Bartram's fanciful account of the inhabitants must have had some foundation in fact, for it is pretty well established that Indians have lived in the swamp. Billy's Island takes its name from Billy Bowlegs, a Seminole chief, who lived on it early in the nineteenth century, and there made his last stand against the whites under Gen. Floyd. On several of the islands are found low hillocks of sand, which are believed to be Indian mounds, but have apparently never been opened. The occupation of parts of the swamp by deserters during the war has already been mentioned. At the present time a large family of white people is said to be living on one of the islands near the head of the Suwannee River.

The country around the Okefinokee is rather sparsely settled. The four counties in which the swamp lies, Charlton, Pierce, Ware and Clinch, averaged in 1900 10.2 inhabitants to the square mile, 66 per cent. of whom were white. The population increased 36 per cent. between 1890 and 1900. Deducting the city of Waycross, which contains

nearly half the population of Ware County, and is the largest city in the pine-barrens of Georgia, the density of population in 1900 was 8.5 per square mile, the proportion of whites 69 per cent., and the increase since 1890 30 per cent. For the whole state of Georgia the corresponding figures were 37.5 per square mile, 53 per cent. white and 21 per cent. increase.

The principal occupations of the people in these counties, outside of the towns, are stock-raising, lumbering, turpentining, farming, hunting and fishing, approximately in the order named. There seem to be a few "moonshiners" just south of the swamp in Florida. Not more than 10 per cent. of the area of the four counties named, even with the swamp excluded, has been touched by the plow as yet. Until quite recently this flat sandy land was considered as little better than a desert, but its merits are beginning to be appreciated, as is proved by the rapid increase of population in the last decade. The leading crops of this region are corn, sugar-cane, oats, sea-island cotton, sweet potatoes and rice. Sugar-cane syrup is becoming one of the principal agricultural exports, especially north and west of the swamp.

Healthfulness of the Region

Like Dismal Swamp and the Everglades, the vicinity of Okefinokee is remarkably free from climatic or endemic diseases, Fountain's statements to the contrary notwithstanding. Malaria, which in the popular mind is commonly associated with swamps of all kinds, seems to be chiefly confined to alluvial districts, and is therefore not to be expected around Okefinokee, which is strictly a non-alluvial swamp. As many as 200 men were sometimes employed in the swamp by the Suwanee Canal Company, and it is said that there was never a case of malaria among them or their families who lived at Camp Cornelia. No one is known to have ever died in the Okefinokee, from illness, snake-bite, starvation, drowning, or any other cause. On the contrary, instances are recorded of men suffering with rheumatism who have gone in there to work and come out in a few days greatly relieved, if not cured.

The chief drawback—though not a serious one—to life in the swamp is the drinking water. It is of course rather warm in summer, and always full of fine particles of peat, just as in northern cedar-swamps, but nevertheless it is not unwholesome. Its properties are doubtless similar to those of the Dismal Swamp water, which used to be preferred by navigators sailing from Norfolk and vicinity because on account of its slightly antiseptic properties it kept fresh on shipboard longer than any other kind.

The flat pine-barrens around the swamp have many attractions as a residential section, notwithstanding the pessimistic picture of them which Bradford Torrey draws in his article "In the Flat-woods."[9]

[9] *Atlantic Monthly*, December, 1893. Also reprinted in his "Florida Sketch-book," 1894, p. 1.

Burns in 1892[10] admits the healthfulness of this kind of country while granting it no other advantage. In White's Statistics (1849) we read that there were no doctors in Wayne County at that time, because none were needed. The universal surface of sand in this region makes it the cleanest country imaginable, especially in wet weather, and also incidentally obviates the necessity of shoeing horses.

The water from shallow wells near the swamp, especially those which penetrate the "hardpan" of the ridge, is not always agreeable to persons unaccustomed to it, but an abundance of good water can be obtained from artesian wells, which are in successful operation at Waycross, Fargo, Moniac and other places.

Economic Aspects

The greatest material resource of Okefinokee Swamp to-day is of course the cypress timber. This cypress, sometimes distinguished as

Scene on Logging Canal.

the pond cypress (*Taxodium imbricarium*), is not the same as the common cypress of commerce (*T. distichum*), but its wood is believed to be a little stronger and heavier if anything. The pond cypress of Okefinokee is not surpassed anywhere for quantity and size, this being near the center of distribution of this species. (The other species seems to center in the lower Mississippi valley.) With conservative methods of exploitation the supply should be practically perpetual. Next to the

[10] Bull. 84, U. S. Geol. Surv., p. 82.

cypress the most important timber is the pine on the islands, but there is still so much of the same outside of the swamp that this comparatively inaccessible supply has not yet been drawn upon for lumber or turpentine. For the various hardwood species which inhabit the swamp there has been as yet almost no demand, and even in the easily accessible small swamps in the surrounding pine-barrens they have scarcely been touched.

The vast quantities of peat in the swamp will doubtless be useful for fuel at some future time, when coal and wood become considerably scarcer than they are now. Capt. Jackson had some of the swamp muck analyzed and found 85 per cent. of it combustible.

Doubtless the most absorbing economic question with regard to Okefinokee Swamp is whether it will be feasible to drain it. The popular demand for indiscriminate drainage of swamps will apparently never be satisfied as long as Okefinokee continues to exist. The arguments against swamp drainage in general, set forth in a recent article,[11] need not be repeated here, but a few points which apply to this swamp in particular deserve to be mentioned.

As the swamp is about 100 feet higher than the St. Mary's River at the other end of the six-mile drainage ditch, it would seem a comparatively simple matter to empty it that way, until it is recalled that the surface of the swamp slopes slightly in the other direction, and most of the water discharges into the Suwannee River. Col. Hunter estimated in 1857 that the swamp could be drained for $1,067,250, but Capt. Jackson, soon after the dredging operations of the Suwanee Canal Company began, expressed the opinion that to drain the swamp thoroughly would require over 300 miles of canals, besides a considerable deepening of the drainage ditch, which is already about 100 feet wide at the top of the ridge.

It was expected that the swamp muck when drained would make a soil of surpassing richness, but experiments made with it where it was thrown up on the banks of the canal gave only negative results. This might have been anticipated from the nature of the surrounding country, which is completely covered with quartz sand, so that the few streams emptying into the swamp carry practically no mineral matter. The sour humus of the swamp might perhaps be dug out and used to advantage on strongly calcareous soils, but there are no such soils within a convenient distance.

A sudden draining of the swamp would be disastrous in several ways. In the first place, it would kill the fish and other aquatic animals, and would probably be detrimental to the health of the surrounding country in other ways. Then it would put an end to the production of cypress timber, for which the swamp seems to be best

[11] *Southern Woodlands*, 2: 46–67, August, 1908. See also *Science*, N. S., 28: 525, October 16, 1908; *Literary Digest*, 37: 890, December 12, 1908.

adapted. Worst of all, fire would soon get in from the surrounding pine forests (which are burned over more or less every year), and consume the muck, timber and all. Several extensive fires have already occurred in the swamp in very dry seasons, it is said, and even at the time of our visit the peaty banks of the canal were smouldering in two or three places.

With game laws properly enforced Okefinokee would be a paradise for the sportsman. Capt. Jackson wrote of it to a friend in the spring of 1892:

> There is no healthier or more attractive spot in the world, to one who can stand exposure and fatigue, than this property. If you are anything of a sportsman, I will show you fishing and hunting that has never had a parallel.

The swamp has been and still is much visited by hunters, and their wantonness has greatly decimated the large game, but none of the species have been exterminated yet, and they would probably soon reestablish themselves if given sufficient protection.

From a scenic standpoint alone Okefinokee is well worth visiting at any season of the year. Its almost untrodden islands, its dense moss-garlanded bays, and its broad open prairies, all have their peculiar charms, and must be seen to be appreciated. There is nothing else exactly like it in the world. There is really more reason for preserving Okefinokee than Niagara, for its destruction would benefit but few people in the long run, and the loss to science would be far greater. It would have been much better if this enchanting wilderness had remained in the possession of the state, to be perpetuated as a forest and game preserve for all future generations.

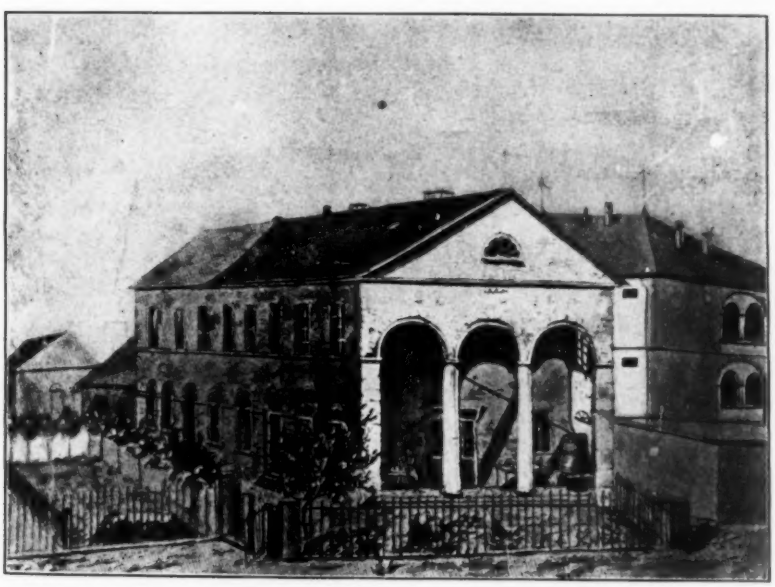
THE PROGRESS OF SCIENCE

JUSTUS VON LIEBIG AND THE FIRST LABORATORY

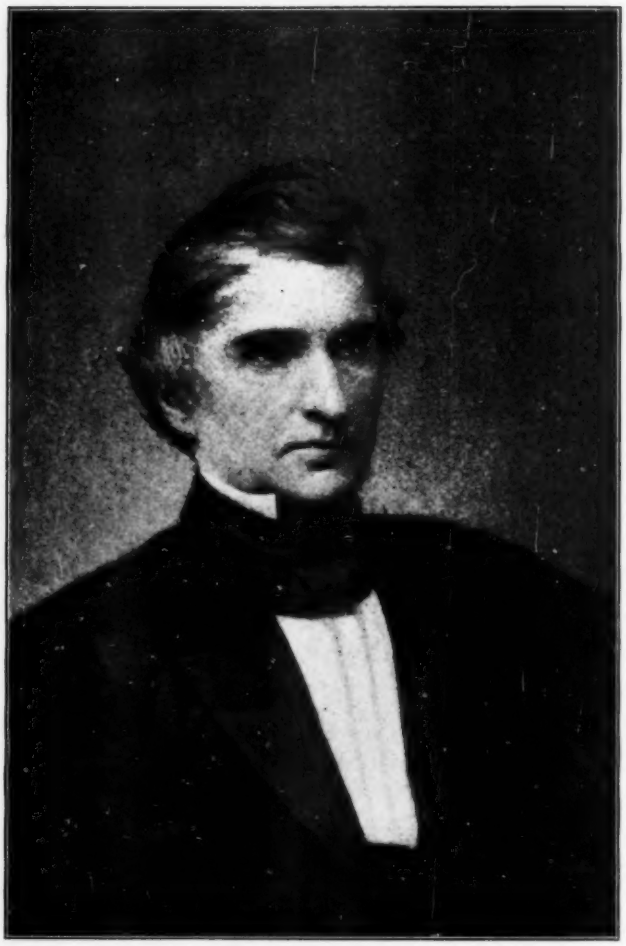
IT has been necessary to wait a long while for a biography of Justus von Liebig, but it has now appeared from the competent hand of Professor Jakob Volhard, of Halle, a chemist of distinction, known also as the biographer of A. W. Hofmann. Liebig and Volhard's father were school friends; the young Volhard was treated almost as a child in Liebig's family; later he was his assistant at Munich and succeeded him in some of his lectures. The biography appears in two large volumes from the publishing house of Barth and contains, in addition to a full personal narrative, an extended account of Liebig's researches in organic chemistry.

As has often happened in the case of those who have become eminent in science, Liebig's father—a dealer in drugs—was engaged in work which influenced the interests of the son; his mother was a woman of character; he was backward in his school studies, but made rapid advances when permitted to take up his chosen work, so that he received his doctor's degree at the age of nineteen and an assistant professorship at the age of twenty-one; he traveled and studied abroad.

At the beginning of the last century there was in Germany a remarkable renascence in letters, philosophy and philology, to be followed a little later by the revival which gave the universities their leading place in the advancement of the natural and exact sciences. Liebig was born in 1803, and when he studied at the university the sciences were dominated by the philosophy of nature of the post-Kantians. He says that he was robbed of two precious years of his life by the infection. Schelling, whose lectures he heard, was



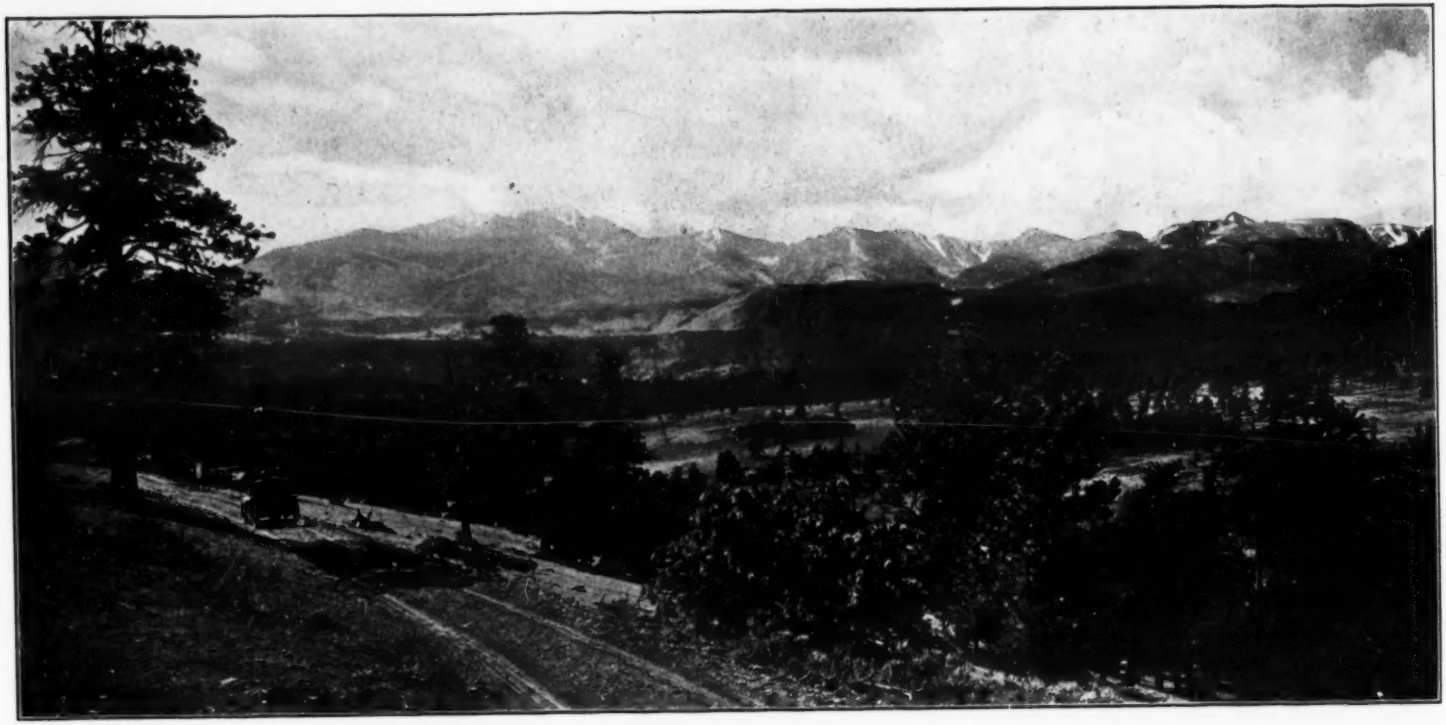
LIEBIG'S LABORATORY AT GIESSEN.



JUSTUS VON LIEBIG.

not likely to lead a student to the study of chemistry. He was capable of writing: "The animal is in organic nature the iron; the plant is the water, for nature begins with the relative separation of the sexes, and then ends in this separation. The animal decomposes the iron, the plant decomposes the water. The female and the male sex of the plant is the carbon and nitrogen of the water." Even Kastner, the professor of chemistry whom Liebig went to Bonn to hear and followed to Erlangen, told his students that "the influence of the moon on the weather is obvious, because storms stop as soon as the moon appears."

But fortunately for science Liebig found his way to Paris and came under the influence of Gay-Lussac. In 1824 he was appointed associate professor of chemistry at Giessen and the following year opened the laboratory of chemistry which is generally regarded as the first regular scientific laboratory for research and instruction. The alchemists had their laboratories and the founders of modern chemistry had rooms in which they carried out their experiments. Anatomical laboratories



for dissection trace their history to Vesalius or even to the beginnings of the medieval university at Salernum. But Liebig's laboratory at Giessen stands for a new epoch in scientific investigation and instruction. It had its own development and was the model for chemical laboratories in other German universities and in other countries. It was some twenty-five years before similar laboratories in physics were established, to be followed still later by laboratories of zoology, physiology, botany, geology and psychology.

It is indeed a long way from "Speculative Physics"—the title which Schelling gave to his work—to the science of the modern laboratory. The transformation in the German university was truly marvelous and is due in greater degree to Liebig than to any other. It was of course a necessary evolution, but a reading of the biography of Liebig makes clear what difficulties had to be overcome and how largely this was accomplished by the energy and personality of the great chemist.

For twenty-seven years Liebig worked in the Giessen laboratory attracting students and fellow workers from all parts of Germany and from foreign countries. He there laid the foundations of organic chemistry and its applications to physiology, to agriculture and to the arts. In 1852 Liebig accepted a call to Munich. He died in 1873.

SCIENTIFIC AND EDUCATIONAL MEETINGS

THE principal scientific congress of the year consists of the scientific societies meeting in affiliation with the American Association for the Advancement of Science in New Year's week, with an attendance in the neighborhood of 2,000 scientific men. The meeting next in importance should be that of the National Academy of Sciences at Washington in the third week of April. The academy has high functions as the adviser of the government in scientific matters and high traditions in maintaining the prestige of science. If, however, the academy transacts business of importance behind closed doors this does not appear in the annual reports, and the scientific programs are small and somewhat uneven in character. At the last meeting there were nineteen papers on the program not all of which were presented. Several of these were important and interesting, and several were important but not interesting to others than experts in the special subject. In general the programs are not of sufficient value to attract to Washington men of science other than members of the academy.

The American Philosophical Society, founded in Philadelphia by Franklin on the model of the Royal Society, after becoming local in character has again undertaken to hold general meetings. They follow immediately those of the National Academy and appear to have become of greater general interest. Thus at the recent meeting there were about fifty papers on the program and some of the events, such as the Darwin memorial session addressed by Ambassador Bryce, were of real significance. The society is fortunate in having its historic building on Independence Square and means to provide luncheons, dinners and receptions. It seems probable, however, that academies having a limited membership selected for eminence and programs covering all the sciences belong to the eighteenth rather than to the twentieth century.

The professional societies in the applied sciences and in education always have successful meetings. The American Medical Convention, meeting in Atlantic City early in June, and the National Educational Association, meeting in Denver early in July, are certain to bring together thousands of members. The National Educational Association not only has programs attractive to teachers, but the excursion elements are emphasized so that the

trip itself is of social and educational value. Many teachers will combine attendance on the sessions at Denver with a visit to the Rocky Mountains, several views of which are here reproduced.

SCIENTIFIC ITEMS

WE record with regret the deaths of Dr. Frank Leo Tufts, A.B., adjunct professor of physics in Columbia University; of Dr. W. H. Edwards, known for his work on the butterflies of North America, and of the Rev. Dr. Sereno E. Bishop, who had made contributions to our knowledge of the Hawaiian volcanoes.

THE following new members of the National Academy of Sciences were elected at the meeting on April 22, 1909: Professor Joseph S. Ames, Johns Hopkins University; Professor Maxime Bôcher, Harvard University; Professor Oskar Bolza, University of Chicago; Mr. Frank W. Clarke, U. S. Geological Survey; Dr. John M. Clarke, New York State Museum; Professor John M. Coulter, University of Chicago; Professor Henry Crew, Northwestern University; Professor Thomas Hunt Morgan, Columbia University; Mr. Waldemar Lindgren, U. S. Geological Survey; Professor Henry L. Wheeler, Yale University. The following were elected foreign associates: Professor Albrecht Penck, University of Berlin; Professor Gustaf Retzius, Stockholm; Professor Wilhelm Waldeyer, University of Berlin; Professor Wilhelm Wundt, University of Leipzig.

THE following new members have been elected to the American Philosophical Society: Louis A. Bauer, William Howard Taft, Washington, D. C.; Marston Taylor Bogert, Hermon Carey Bumpus, Dr. Alexis Carrel, A. V. Williams Jackson, New York; Edwin Brant Frost, Williams Bay, Wis.; Robert Almer Harper, Charles Richard Van Hise, Madison, Wis.; William Herbert Hobbs, Victor Clarence Vaughan, Ann Arbor, Mich.; Abbott Lawrence Lowell, Boston; William Romaine Newbold, John Frederick Lewis, Charles Bingham Penrose, Philadelphia; Francis Darwin, Cambridge, England; Hermann Diels, Emil Fischer, Berlin; Friedrich Kohlrausch, Marburg; Wilhelm F. Ph. Pfeffer, Leipzig.

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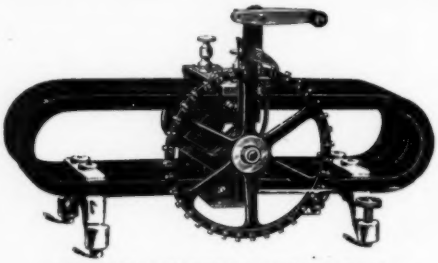

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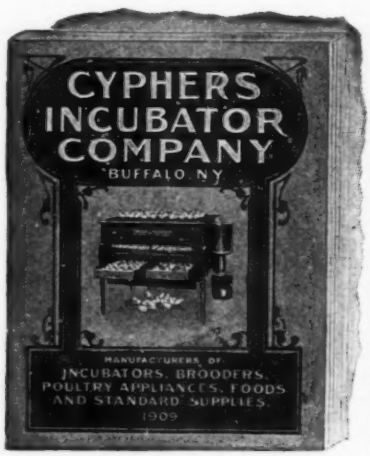

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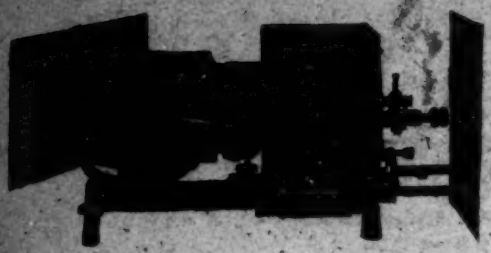

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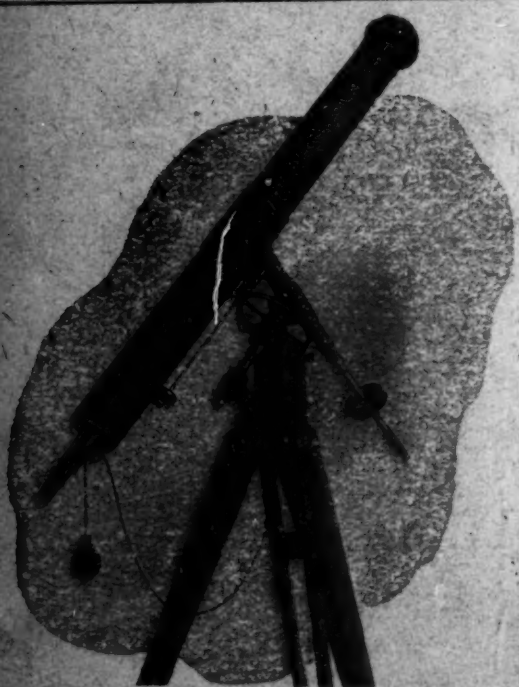

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